LONG-LIVED LEGACY

Managing High-Level and Transuranic Waste at the DOE Nuclear Weapons Complex

BACKGROUND PAPER

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Foreword

This background paper is a technical annex to the main OTA report *Complex Cleanup: The Environmental Legacy of Nuclear Weapons Production*. It describes, documents, and analyzes available data about two key waste management problems at the Department of Energy Weapons Complex—those of high-level radioactive waste and transuranic waste. The paper is organized in two chapters—"Chapter 1: Managing High Level Waste" and "Chapter 2: Managing Transuranic Waste." Each chapter contains a summary overview followed by a discussion and analysis of important areas in the waste management problem that the DOE faces at present and in its future operations.

DOE has made significant investments in waste management throughout the Weapons Complex in the past, and those investments are likely to grow in the future. The 1990 Five-Year Plan calls for almost $20 billion in waste management expenditures (about two-thirds of the total in the plan) over the next 5 years. Major new facilities are nearing completion and plans for additional facilities have been put forward. The challenge for DOE is to develop more effective practices for managing both current and future waste in order to avoid repeating the serious problems of the past.

In this assessment, OTA has focused on high-level and transuranic waste because these forms often pose the most risk, they are essentially unique to DOE, and the bulk of DOE's waste management resources will be devoted to them. Large quantities of other wastes are also generated throughout the Weapons Complex (i.e., low-level radioactive waste and hazardous waste), and a comprehensive approach to all waste management must be followed by DOE. This background paper, therefore, reviews only some of the critical areas and aspects of the DOE waste problem in order to provide data and further analysis of important issues covered in the main OTA report.

As noted above, this paper is part of a broader assessment of environmental restoration and waste management at the DOE Nuclear Weapons Complex and was used to provide background material for input to the larger assessment. Information for the study was obtained from DOE and DOE contractor personnel, the Environmental Protection Agency, the National Academy of Sciences, citizens groups, academics, other independent organizations, and a variety of media. Visits to obtain information and observe practices firsthand were made to the Savannah River Site, the Hanford Reservation, West Valley, NY, the Waste Isolation Pilot Plant, Los Alamos National Laboratory, Sandia National Laboratory, the Environmental Evaluation Group, and the Idaho National Engineering Laboratory. We are grateful to all who provided information and to the reviewers who raised many valuable questions about earlier drafts.

Detailed analysis and in-depth information about the entire DOE waste management program is available largely from DOE itself. The subject is extensive and complex with a long history, some of which is undocumented in the public literature. The data that are available are often in a form that is difficult to access, assemble, summarize, and interpret. While it may be useful for some agency to investigate this subject more thoroughly, OTA concluded that the analysis contained herein would be most useful for congressional policymakers at this time.

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Chapter 1

High-Level Waste Management at the DOE Weapons Complex

OVERVIEW

The first high-level defense waste was created as a byproduct of the production of plutonium in a natural uranium-graphite reactor at Hanford and the subsequent remote "reprocessing" of irradiated uranium fuel elements to recover plutonium. The byproduct was a highly radioactive, acidic, aqueous solution containing a variety of fission products with a wide range of half-lives, as well as residual uranium and some residual radionuclides with larger atomic numbers than uranium—the transuranics. It was recognized that this liquid high-level waste (HLW) required careful handling, as well as isolation from people and the environment for many years. HLW is generally distinguished from other radioactive waste types by its intense radioactivity coupled with the longevity of its hazard. Huge, underground, single-shell carbon steel tanks, eventually 149 in number, were built to store neutralized liquid HLW at Hanford. An early practice of discharging some of the liquid from the HLW tanks into "cribs" and then into the soil was subsequently discontinued. When some tanks began to leak, new tanks of double-shell design were added.

Today, most liquid HLW has been neutralized, forming mixtures of liquid, sludge, and salt cake, and is currently stored on-site in steel tanks, some of which have leaked and represent a potential threat to groundwater. Storage of waste in less expensive carbon steel, rather than stainless steel, tanks after neutralization of acidic HLW requires complicated waste handling and treatment. There is also concern about the possibility of fire or explosion in the waste tanks, accompanied by the release of radioactivity.

Four Department of Energy (DOE) sites have HLW: the Hanford Plant, the Savannah River Site, the Idaho National Engineering Laboratory (INEL), and West Valley, NY; the last, a nonweapons site, reprocessed some fuel commercially from 1966 to 1972. The prime contractors for the management of HLW at all four sites are subsidiaries of Westinghouse. Two sites have more than 90 percent of the HLW by both volume and radioactivity—Savannah River and Hanford—and are planning to begin operations to immobilize HLW in 1992 and 1999,[1] respectively, although slippage of these schedules would not be unusual. The Savannah River vitrification facility was built at a cost of about one billion dollars. The Hanford facility is not yet constructed but plans call for it to be very similar to Savannah River. The West Valley site is also scheduled to begin vitrifying waste in 1996; the cost of all West Valley operations, including decontamination and modification of existing facilities to accommodate vitrification as well as new construction needed for the vitrification plant, will be on the order of one billion dollars. Canisters of vitrified waste ("glass logs") are to be stored on-site, pending disposal in a deep geologic repository that is not expected to begin operation until the second decade of the 21st century. In contrast to the other three sites, for 25 years INEL has been converting liquid HLW from the reprocessing of highly enriched uranium-235 spent fuel, from naval and other reactors, to a powdery solid calcine and storing it in stainless steel bins; DOE has not made a final decision about the waste form for immobilization and disposal of INEL HLW.

At West Valley, DOE is reducing the volume of high-level tank waste to be vitrified by separating a portion of the waste that DOE believes qualifies as low-level waste, mixing it with cement, and temporarily storing it in drums above ground, pending a disposal decision through the Environmental Impact Statement (EIS) process. An analogous separation is planned for Savannah River and Hanford because it will greatly reduce the amount of waste to be vitrified and should substantially reduce disposal costs if the portion immobilized in grout or concrete can be disposed of on-site at or near the surface. At West Valley, DOE sought and obtained Nuclear Regulatory Commission (NRC) approval to perform such a separation; NRC has oversight authority under the West Valley Demonstration Act of 1980. However, there appears to be no such NRC authority at the weapons sites. Concerns have been raised by interested members of the public about the safety of such waste separation; the grouted waste at West Valley is reported to be "Class C low-level waste" containing technetium-99, a long-lived (210,000-year half-life) beta emitter. In South Carolina, nevertheless, DOE is moving ahead, indicating that it has all necessary permits from the State to begin "saltstone" operations at Savannah River; by July 1990, those operations were underway but not using waste from the main high-level tank farm.

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[1] In February 1991, a 2-year delay in operation of the Hanford Vitrification Plant was announced by DOE.

Uncertainty exists about the composition of HLW at DOE weapons sites. The uncertainty arises because of the variety of processes that have been used, the past mixing of wastes, and the heterogeneity of tank components after neutralization. Sampling is very difficult because of tank design, the high radioactivity levels, and concern about the possibility of tank explosions. Knowledge of waste composition is important in designing waste treatments and it is needed for proper glass-waste formulation for the vitrification process.

Historically, DOE has regulated HLW at weapons sites under the Atomic Energy Act.[2] However, EPA has become a major factor in regulating waste management at the weapons sites through its jurisdiction over hazardous waste and application of the Resource Conservation and Recovery Act (RCRA) and the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) to these sites. State agencies have also become involved under RCRA and through mechanisms such as interagency agreements under CERCLA.

The basic thrust of the HLW management program of DOE is to move from the present less secure, less stable, less controlled condition to a more stable one by immobilizing the tank waste. HLW vitrification, if successful, should reduce the threat of groundwater contamination and tank explosions posed by liquid HLW stored in tanks. An objective of vitrification is to produce a waste form that will immobilize waste safely for hundreds or thousands of years; however, the process chosen, involving borosilicate glass, has yet to operate on a large scale in the United States,[3] and long-term performance of the vitrified waste form in various settings is difficult to predict and hard to verify. If vitrification works as planned, the glass logs produced represent a potentially stable form for long-term storage on-site or in a monitored retrievable facility if the deep geologic repository should be delayed. DOE and most experts working within the DOE program believe that, at present, vitrification using borosilicate glass is the best available technology for geologic disposal. However, some concerns have been raised about whether DOE will be able to demonstrate that borosilicate glass will perform as required in the Yucca Mountain repository environment.

The Transition to More Stable Waste Form

A significant transition is beginning to take place from the less secure and more threatening storage of HLW in tanks to the more promising secure storage of immobilized HLW in solid, glasslike form. Bringing about this transition is a major and costly undertaking, and a successful outcome is far from being achieved. However, if it can be accomplished with minimal occupational risk to workers, it should greatly reduce if not remove the current, ever-present threat and concern regarding tank leaks and explosions. The nominal design lifetime of vitrified waste using borosilicate glass is such that even if a geologic repository were delayed significantly, the glass logs could be stored safely on-site at Savannah River and Hanford for hundreds of years, as long as the necessary institutional controls remain in place. Calcine, even without immobilization in glass or ceramic, also appears able to be safely stored for hundreds of years at INEL.

The legacy of past practices in which HLW was discharged into cribs or stored in 149 single-shell tanks at Hanford must still be dealt with; DOE has not yet decided how to accomplish the necessary decontamination and safe disposal.

Monitoring the Waste Forms

Because of the importance and the cost of vitrification to improve the safety and stability of HLW storage and disposal, it is essential to carefully monitor and regulate the integrity and hazard potential of the waste forms, including both vitrified and concrete products. Continuing studies and monitoring are required to resolve opposing claims that may arise concerning safety and health risks during storage, along with a continued strong research program on waste stability,[4] container integrity, and radionuclide transfer through the environment.

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[2] 42 U.S.C. §§2011-2296 (1982 and Supp. IV 1986).

[3] There is, however, considerable experience with commercial HLW vitrification in Europe, especially France, using a process somewhat similar to that built at or planned for these DOE facilities.

[4] Factors concerning waste stability over the long term that need investigation include leaching, embrittlement, and corrosion.

Form of HLW at the Idaho National Engineering Laboratory

At INEL, DOE followed a very different waste management approach and decided to produce a dry, calcined waste form for the storage of HLW. This decision provided considerable experience with an alternative to the approach used at Hanford and Savannah River. The calcined waste form has proved suitable for interim storage. For ultimate disposal, work is focusing on glass ceramic as a promising medium for immobilization of the calcine in order to reduce disposal costs relative to the use of borosilicate glass. Cost, although important, is but one factor to be considered. Environmental integrity in response to evolving, possibly tightened environmental standards for radioactivity is another.

Calcining appears to be a proven, relatively low-cost means of solidifying liquid waste and a viable medium-term (about 500 years) alternative to vitrification. More research on the calcined waste form and on bin hardening of calcine for disposal could supply data for use if some future treatment, storage, and/or disposal alternatives were considered.

HLW Repository

The U.S. approach to HLW disposal is to license and use a geologic repository to contain potentially harmful radionuclides for the tens or hundreds of thousands of years that may be necessary. The Swedish approach places more reliance on engineered barriers, including a thick container wall to provide the necessary isolation; other European countries are also focusing on engineered barriers. By contrast, in the United States, current policy places reliance on the geologic repository itself.

The U.S. high-level defense waste glass logs are to be formed in thin-walled canisters that meet NRC repository criteria; the canisters will then be put in containers before repository emplacement. One issue is whether to place more reliance on engineered barriers for isolating the waste, for example, by increasing either canister thickness or container thickness and backfill, or by some combination of these modifications for the geologic repository setting. Factors to consider include cost, interaction between barriers and the chosen repository environment, and the fact that both defense HLW and commercial spent fuel are now required to use the same container design.

Standards for HLW Disposal

Standards for disposal of HLW have been remanded by the courts but are expected to be reissued for comment by the Environmental Protection Agency (EPA).[5] These standards have important implications for defense HLW. The long-term trend has been to issue progressively more stringent standards for nuclear waste disposal as new information becomes available about health risks from radiation exposure. This trend may continue but the process is very slow and thus has affected planning for ultimate safe disposal.

Timeframe for Immobilization

Decisions about the urgency and rapidity with which liquid high-level tank waste should be immobilized are difficult to make because of the lack of good information on the contents of some tanks or on the movement of radioactive and hazardous materials that have leaked from tanks. In the absence of such information, and given continuing concern about the possibility of waste tank explosions, it may be prudent to move forward with vitrification projects as quickly as feasible and to make sure that technical, environmental, and policy questions or concerns are addressed promptly and effectively as well. Trade-offs between moving ahead with dispatch and moving ahead too precipitously require careful consideration. Among the current concerns is the possibility of explosion when disturbing or heating tanks or tank contents. Also, occupational radiation doses should be carefully controlled and monitored.

Airborne Releases

Airborne release of both radioactive and hazardous materials is a significant potential health threat from DOE weapons sites. The movement of contaminants in the air is direct and rapid compared with movement via groundwater. Reactors, reprocessing plants, and HLW treatment operations all involve some routine air emissions; in addition, there is the possibility of accidental release. Although air releases have been greatly reduced from the early days of the weapons program, attention to air emissions is continually important, both in setting standards and in monitoring waste management activity.

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[5] Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes, 40 C.F.R. §191 (1989).

Future of the PUREX Plant at Hanford

The Plutonium and Uranium Extraction (PUREX) fuel reprocessing plant has been of concern because of its age, the large amounts of hazardous and radioactive wastes it produces, past atmospheric releases, and continued release of liquid effluents to the soil. In early 1990 DOE had plans to restart PUREX to reprocess backlogs of spent defense fuel over a 5-year period and then to close the facility permanently. A principal reason for this was concern about the 2,100 metric tons of metallic spent fuel from the Hanford N reactor awaiting reprocessing and currently being held in water basins at K plant, near the Columbia River. DOE needs to prevent any radionuclide release from failed fuel elements since these basins have leaked in the past.

In October 1990, DOE announced that it would not restart PUREX for at least 2 years, but would prepare an Environmental Impact Statement (EIS) to evaluate a variety of treatment and disposal methods for stored N reactor fuel.[6] Some have interpreted this announcement as indicating that PUREX will never again operate.[7] The EIS process requires full consideration with public input of the impact of alternatives to restart, including the consequences of continued storage of fuel elements in the K basins.

Learning From International Experience

Since the U.S. decision in the 1970s not to encourage reprocessing of commercial nuclear fuels, other nations have moved ahead in acquiring expertise in reprocessing that could prove useful to DOE's fledgling efforts at waste minimization. Learning from these international sources could be part of a necessary upgrading of DOE waste minimization activity, particularly in planning for any new reprocessing capability in connection with modernization of the Weapons Complex.

INTRODUCTION AND DEFINITIONS

High-level radioactive waste is a consequence of the materials and methods used by the United States to produce plutonium and tritium for nuclear weapons. Neither substance occurs in nature, and both are produced by neutron capture in nuclear reactors. For these reactors to operate, neutron chain reactions must occur, which require that fission takes place in one or more heavy isotopes of uranium. Fission produces numerous elements—strontium-90 and iodine-131 are two examples—that are radioactive. Each time a fission event occurs, two (or occasionally three) radioactive fission products are formed.

In the United States, the high-level waste (HLW) found in defense facilities differs from its spent fuel counterpart found in the commercial sector. Commercially, fission products, uranium and transuranic isotopes, are contained in irradiated fuel elements removed from reactors—so-called *spent fuel*—that (with the exception of a plant operating intermittently in West Valley, NY from 1966 to 1972) have not been subjected to *reprocessing*. In reprocessing, fuel elements are chopped up and dissolved; plutonium and, in some cases, uranium are separated from the fission products for reuse in a reactor. Spent fuel in the U.S. commercial sector is stored at reactor sites pending development of a deep geologic repository for its disposal. In this report, spent fuel is not considered to be a form of, or to fall within the definition of, defense HLW. However, spent fuel is present at some Department of Energy (DOE) weapons sites.[8]

High-level waste is defined by a DOE order as "the highly radioactive waste material that results from the reprocessing of spent nuclear fuel, including liquid waste produced directly in reprocessing and any solid waste derived from the liquid, that contains a combination of transuranic waste and fission products in concentrations requiring permanent isolation" (63). Box 1-A compares this and other definitions of high-level waste.

Defense HLW arising from reprocessing of fuel elements or irradiated targets (see figure 1-1) leaves the reprocessing plant as highly radioactive liquid that usually contains more than 99 percent of the nonvolatile fission products from the fuel elements or targets during their time in the reactor. It also contains roughly 0.5 percent of plutonium and 0.5 percent of the uranium that was present in the spent fuel, if both these elements are recovered in the reprocessing operation (3). The radioactive liquid is stored in tanks, pending conversion to a glassy solid by a process known as *vitrification*. The major exception to this waste form conversion is at the Idaho National Engineering Laboratory (INEL) where some HLW liquids have been subject to *calcination*, producing a powdery solid that is not generally considered to be in final form for disposal.

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[6] N.K. Geranios, "Plutonium Processing Plant Won't Reopen, Energy Secretary Says," Associated Press News Release, Oct. 17, 1990.

[7] C. Holden (ed.), "Bailing Out of the Bomb Business," *Science*, Nov. 9, 1990, p. 753.

[8] App. C of the DOE Integrated Data Base (IDB) for 1989 lists spent fuel elements at the DOE weapons sites for which no reprocessing is planned. Included are some irradiated, damaged fuel elements. The IDB does not list spent fuel scheduled to be reprocessed that is present at the weapons sites. See U.S. Department of Energy, "Integrated Data Base for 1989: Spent Fuel and Radioactive Waste Inventories, Projections and Characteristics," DOE/RW-0006, November 1989.

The only way to turn off the HLW source term (the ultimate in HLW *waste minimization*) is to stop producing plutonium and tritium, to produce them by methods completely different from those currently used, or to utilize a substitute for plutonium whose production does not require a nuclear reactor. For example, uranium-235, which occurs in nature could, in principle, replace plutonium if the need for new fissionable material arose. Plutonium might be recovered from existing materials in the civilian reactor program, but that would violate a long-standing policy of separation of military and civilian nuclear activities. Tritium,[9] although not essential for weapons, makes them smaller and enhances their explosive yield; it could conceivably be made in a linear accelerator rather than a reactor.

The feasibility of alternatives to current nuclear weapons materials and production methods is not explored here. However, the intense radioactivity of HLW is a direct consequence of present production methods, and HLW minimization is difficult at current facilities. As of late 1990, no high-level defense waste was being generated anywhere in the DOE complex, although reprocessing facilities at Savannah River and Idaho were scheduled to resume operations and small amounts of research reactor fuel were being reprocessed at Savannah River.[10] In January 1990, DOE agreed to perform a programmatic Environmental Impact Statement (EIS) of its plans for modernizing weapons facilities and that process began in late 1990 (25).

Box 1-A—Definitions

***High-Level Waste*: The highly radioactive waste material that results from the reprocessing of spent nuclear fuel, including liquid waste produced directly in reprocessing and any solid waste derived from the liquid, that contains a combination of transuranic waste and fission products in concentrations requiring permanent isolation.**

***Spent (Nuclear) Fuel*: Fuel that has been withdrawn from a nuclear reactor following irradiation, but that has not been reprocessed to remove its constituent elements.**

***Transuranium (Transuranic) Radionuclide*: Any radionuclide having an atomic number greater than 92.**

SOURCE: DOE Order 5820.2A.

Two Other Definitions of High-Level Waste

***Nuclear Regulatory Commission*: 1) irradiated reactor fuel; 2) liquid wastes resulting from the operation of the first cycle solvent extraction system, or equivalent, and the concentrated wastes from subsequent extraction cycles, or equivalent, in a facility for reprocessing irradiated reactor fuel; and 3) solids.**

SOURCE: 10 CFR Part 60.

***Nuclear Waste Policy Act of 1982 (NWPA)*: A) The highly radioactive material resulting from the reprocessing of spent nuclear fuel, including liquid waste produced directly in reprocessing and any solid material derived from such liquid waste that contains fission products in sufficient concentrations; and B) other highly radioactive material that the [Nuclear Regulatory] Commission, consistent with existing law, determines by rule requires permanent isolation.**

SOURCE: Public Law 97-425.

Unlike civilian HLW which is "locked up" in solid fuel elements, defense HLW is currently stored in tanks, either as liquid or a form resulting from waste neutralization and liquid evaporation, including sludge, salt cake, and slurry. Some of these tanks were built in 1943; some have already leaked. The composition of waste in some tanks is not well known, and concerns have been raised about possi-

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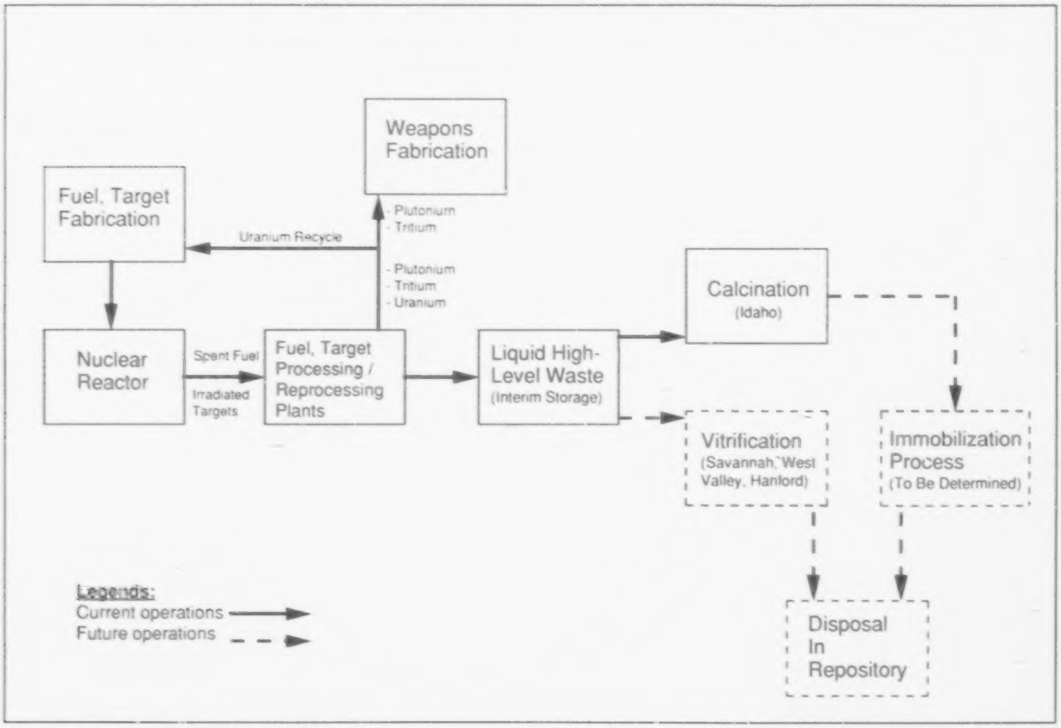
[9] Tritium can be produced in reactors without reprocessing the driver fuel elements; hence no HLW would be produced, as the term is defined in this paper. However, highly radioactive spent fuel is produced that must eventually be disposed of.

[10] In October 1989, Energy Secretary James D. Watkins announced that the PUREX reprocessing plant at Hanford would be placed on standby for at least 2 years (see N.K. Geranios, op. cit., footnote 6). Reprocessing of small amounts of research reactor fuel from Taiwan and U.S. commercial test reactor fuel was being carried out at Savannah River (personal communication to P. Johnson, OTA, Oct. 26, 1990).

Figure 1-1—Schematic of High-Level Waste Generation, Treatment, and Disposal


Weapons Fabrication
Fuel, Target Fabrication
- Plutonium
- Tritium
Uranium Recycle
- Plutonium
- Tritium
- Uranium
Calcination
(Idaho)
Nuclear Reactor
Spent Fuel
Irradiated Targets
Fuel, Target Processing / Reprocessing Plants
Liquid High-Level Waste
(Interim Storage)
Vitrification
(Savannah, West Valley, Hanford)
Immobilization Process
(To Be Determined)
Legends:
Current operations
Future operations
Disposal In Repository

SOURCE: Office of Technology Assessment, 1991.

ble tank explosions. Both the double-shell and single-shell tanks at Hanford, Savannah River, Idaho, and West Valley pose a continuing technical and economic challenge for the environmental cleanup and waste management agenda.

HIGH-LEVEL WASTE AT DEPARTMENT OF ENERGY SITES

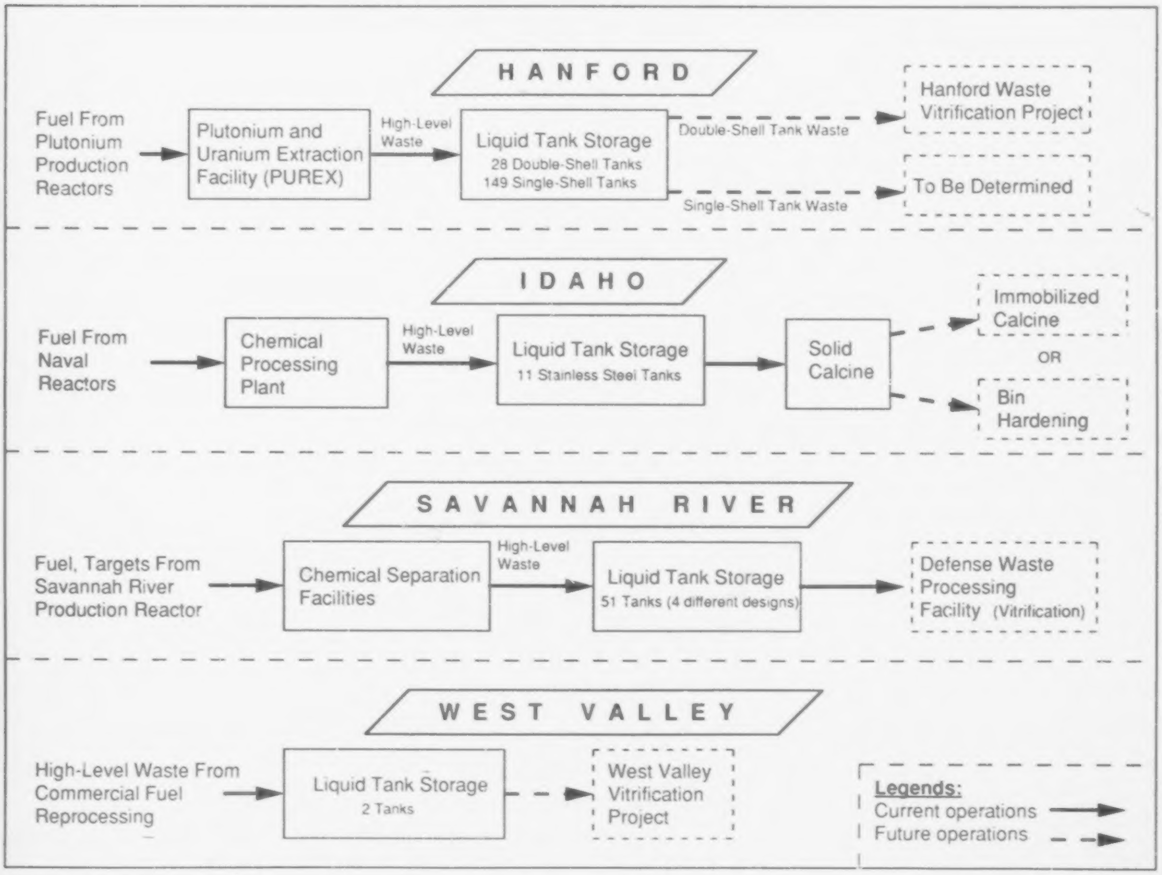
High-Level Waste Management: Present and Planned

Figure 1-2 illustrates the present generation and management of HLW at DOE facilities. When all facilities are operating, wastes are generated by reprocessing and stored as liquids in tanks at three sites: Hanford, Idaho, and Savannah River. DOE through its Idaho Operations Office has also assumed principal responsibility for managing the high-level commercial waste generated at West Valley, NY. Currently, at all four locations, the principal DOE contractor for managing the HLW is associated with Westinghouse. Technical support to DOE headquarters for the HLW management program is supplied by the BDM Corp.

The essence of DOE's strategy for managing HLW, described in the 1989 Five-Year Plan (52), is to move from the current situation in which most HLW is in tanks as liquid, sludge, or salt cake to a situation in which the waste is immobilized, put in stainless steel canisters, and eventually shipped to a deep geologic repository for disposal. According to DOE, "Vitrification and calcining are two demonstrated methods for treating HLW for storage and/or disposal" (52).

In its 1989 Five-Year Plan, DOE characterized vitrification as follows: vitrification produces a glasslike form with "long-term stability." Extensive research undertaken in fiscal year (FY) 1983, which included consideration of about 15 different waste forms, resulted in DOE selection of borosilicate glass as a suitable final HLW form. After vitrification, waste is poured into stainless steel canisters that are sealed and stored until a geologic repository becomes available. Three facilities are planned to use this vitrification process: 1) the Defense Waste Processing Facility (DWPF) at Savannah River, 2) the West Valley Demonstration Project (WVDP), and 3) the Hanford Waste Vitrifi-

Figure 1-2—High-Level Waste at DOE Facilities


HANFORD
Fuel From Plutonium Production Reactors
Plutonium and Uranium Extraction Facility (PUREX)
High-Level Waste
Liquid Tank Storage
28 Double-Shell Tanks
149 Single-Shell Tanks
Double-Shell Tank Waste
Hanford Waste Vitrification Project
Single-Shell Tank Waste
To Be Determined
IDAHO
Fuel From Naval Reactors
Chemical Processing Plant
High-Level Waste
Liquid Tank Storage
11 Stainless Steel Tanks
Solid Calcine
Immobilized Calcine
OR
Bin Hardening
SAVANNAH RIVER
Fuel, Targets From Savannah River Production Reactor
Chemical Separation Facilities
High-Level Waste
Liquid Tank Storage
51 Tanks (4 different designs)
Defense Waste Processing Facility (Vitrification)
WEST VALLEY
High-Level Waste From Commercial Fuel Reprocessing
Liquid Tank Storage
2 Tanks
West Valley Vitrification Project
Legends:
Current operations
Future operations

SOURCE: Office of Technology Assessment, based on U.S. Department of Energy data, 1990.

cation Project (HWVP). The DWPF and West Valley facilities represent priority 1 of the 1989 Five-Year Plan, that is, "ongoing waste management activities that, if they were interrupted, could lead to near-term adverse impacts on workers, the public, or the environment" (52). The HWVP, because it is subject to an agreement among the Environmental Protection Agency (EPA), the State, and DOE and physical construction has not begun, is priority 2; the latter "adds waste management activities that directly respond to agreements between DOE and State or Federal regulatory bodies" (52). Start dates for the operation of vitrification facilities are DWPF, FY 1992; West Valley, FY 1995; HWVP, after FY 2000 (52).

DOE plans to pretreat the high-level liquid waste streams at Hanford, Savannah River, and West Valley to reduce the volume of waste to be vitrified. Pretreatment involves evaporation and separation of a "low-level" fraction to be disposed of by mixing with cement to make a concrete or grout that is subsequently placed in a disposal facility at or near the surface. Facilities for pretreatment have been constructed; some startup operations have begun at Hanford and Savannah River, whereas immobilization with cement is quite far along at West Valley. The "low-level" grout material at Hanford is subject to mixed waste regulation under the Resource Conservation and Recovery Act (RCRA). However, DOE contends that the Savannah River grout is a "non-hazardous waste form and qualifies for disposal in an industrial waste landfill."[11]

Calcination solidifies liquid waste by spraying droplets onto hot particles, resulting in a granular end product that is transferred to stainless steel bins encased in near surface concrete vaults. In the process, the volume is reduced eightfold (9). Calcining operations began at the Idaho Chemical Processing Plant (ICPP) in 1963. The newest facility, the New Waste Calcining Facility (NWCF) that came on line in 1982, has calcined more than 2 million gallons of liquid waste (73). The NWCF has had two extended shutdowns and was not operating throughout most of 1990 (35). According to the 1989 Five-Year Plan, although calcined waste is suitable for extended storage (400 to 500 years in the current stainless steel bin-concrete vault arrangement).[12] ". . . DOE has not determined its acceptability for final disposal" (15). Calcined waste is "readily retrievable and, if necessary, will be immobilized for disposal." Design of an immobilization plant is due to start in FY 2002 "if this is the decision of DOE"; the treatment method is unknown (52). DOE appears to be leaning toward a glass ceramic as the preferred final waste form.

Conditions of HLW storage is described in the 1989 Five-Year Plan (53). All HLW is mixed waste. Double-shell tanks at Hanford and Savannah River containing liquid waste meet RCRA requirements. However, new tank construction is planned for INEL. "Double-shell (double containment) tanks for liquids, salts and sludges at the Hanford Site and the Savannah River Site and stainless steel bins at the Idaho National Engineering Laboratory (INEL) for dry calcine provide high integrity storage pending final treatment and disposal of high-level waste." At INEL,storage tanks and concrete containment vaults were built about 35 years ago. They are still sound but do not meet current earthquake standards or RCRA secondary containment rules. A major effort is planned, beginning in FY 1991, to design and build four new 500,000-gallon stainless steel tanks for liquid waste at INEL, to replace some of the current ones (53).

Both DWPF and HWVP will include storage capability for vitrified waste, with the ability to add additional storage space until the geologic repository is ready to receive HLW for disposal. Plans for the final HLW form at INEL are still under development. "Shipments to the repository will fulfill DOE's long-term goal of ending the need for interim storage of high-level waste" (54). "High-level waste is to be immobilized and disposed of using highly reliable isolation technology—a deep geologic repository" (55). Present efforts focus on a site at Yucca Mountain, NV. However, according to a 1989 Nuclear Regulatory Commission (NRC) assessment, such a facility may not be ready until the second decade of the 21st century.[13] According to the 1989 Five-Year Plan, recent EPA restrictions on storage mean that if disposal is not accomplished, operations could be curtailed. As a waste producer, DOE must obtain approval from the NRC to place waste in a repository that will house the Nation's spent commercial fuel. DOE must also pay a share of the repository costs (55).

Amount and Distribution

Figures 1-3 and 1-4 show the distribution of HLW at DOE sites by volume and radioactivity. Of the four locations with high-level waste, Hanford and Savannah River have a combined total of more than 90 percent of the waste, as measured by both volume and radioactivity. Idaho (ICPP) has 5.6 percent of the total radioactivity and 2.9 percent of the total volume. The fourth site, West Valley, has the smallest amount, occupying one large carbon steel tank and one small stainless steel tank. However, solidifying this "small" amount, along with decontaminating the old fuel reprocessing facility and converting it to a vitrification plant, will cost about one billion dollars (45).

For purposes of comparison, high-level defense waste is estimated to contain 1.17 billion curies (Ci), some 40 times the radioactivity of commercial HLW but one-sixteenth the radioactivity of commercial spent fuel.[14] With the exception of 3,400 cubic meters (m^3) of solid calcine stored in stainless steel bins at Idaho and a small volume of separated strontium-90 (Sr^{90}) and cesium-137 (Cs^{137}) in stain-

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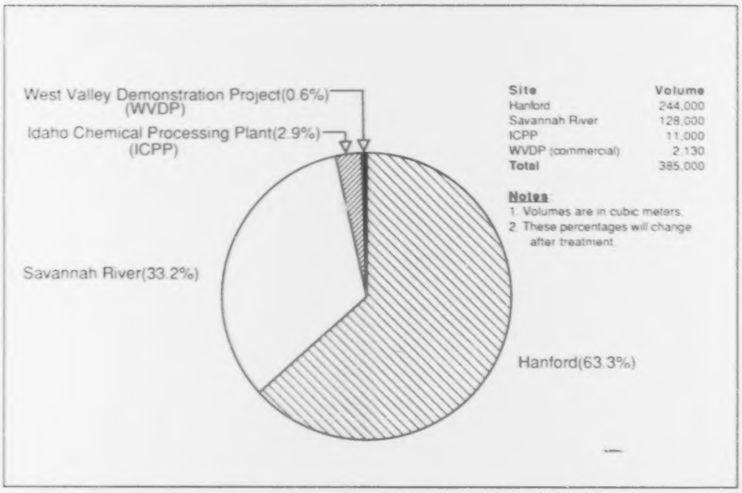
[11] S.P. Cowan, U.S. Department of Energy, personal communication to R.P. Morgan, Mar. 21, 1990.

[12] J. Solecki, U.S. Department of Energy, "INEL Waste Management Strategies," presentation and viewgraphs, July 28, 1989.

[13] Waste Confidence Decision Review—Proposed Revision of Waste Confidence Decision, 54 Fed. Reg. 39767, 39783 (1989).

[14] Spent fuel at DOE sites is not included in the definition of defense HLW, nor does the IDB provide any comprehensive information on the amount of defense spent fuel at DOE weapons sites.

Figure 1-3—Total Volume of High-Level Waste Through 1988

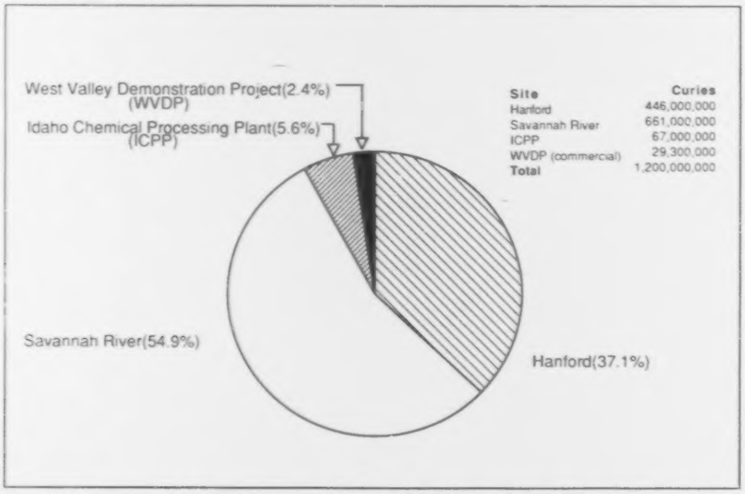


Site	Volume
Hanford	244,000
Savannah River	128,000
ICPP	11,000
WVDP (commercial)	2,130
Total	385,000

Notes:
1. Volumes are in cubic meters.
2. These percentages will change after treatment.

SOURCE: U.S. Department of Energy, "Integrated Data Base for 1989," DOE/RW-0006, November 1989.

Figure 1-4—Total Radioactivity of High-Level Waste Through 1988



Site	Curies
Hanford	446,000,000
Savannah River	661,000,000
ICPP	67,000,000
WVDP (commercial)	29,300,000
Total	1,200,000,000

SOURCE: U.S. Department of Energy, "Integrated Data Base for 1989," DOE/RW-0006, November 1989.

less steel capsules stored underwater at Hanford, all HLW is stored in steel tanks. These exceptions amount to more when their radioactivity is considered: 4.8 percent of the total HLW radioactivity at Hanford, Idaho, and Savannah River is found in the Idaho calcine, and 15.1 percent is found in the strontium and cesium capsules.

Some 128,000 cubic meters (339 million gallons) of HLW at Savannah River is stored in carbon steel tanks. The radioactivity is distributed among four phases: liquid, sludge, salt cake, and precipitate, with sludge containing 60.5 percent of the radioactivity.

At Hanford, 149 single-shell tanks contain an estimated 157 million curies of radioactivity.[15] Some of these tanks were initially designed to cascade (discharge) waste into cribs, followed by percolation through soils so that the radioactive material would be retained in the soil. This practice was discontinued after the 1950s, when evaporators

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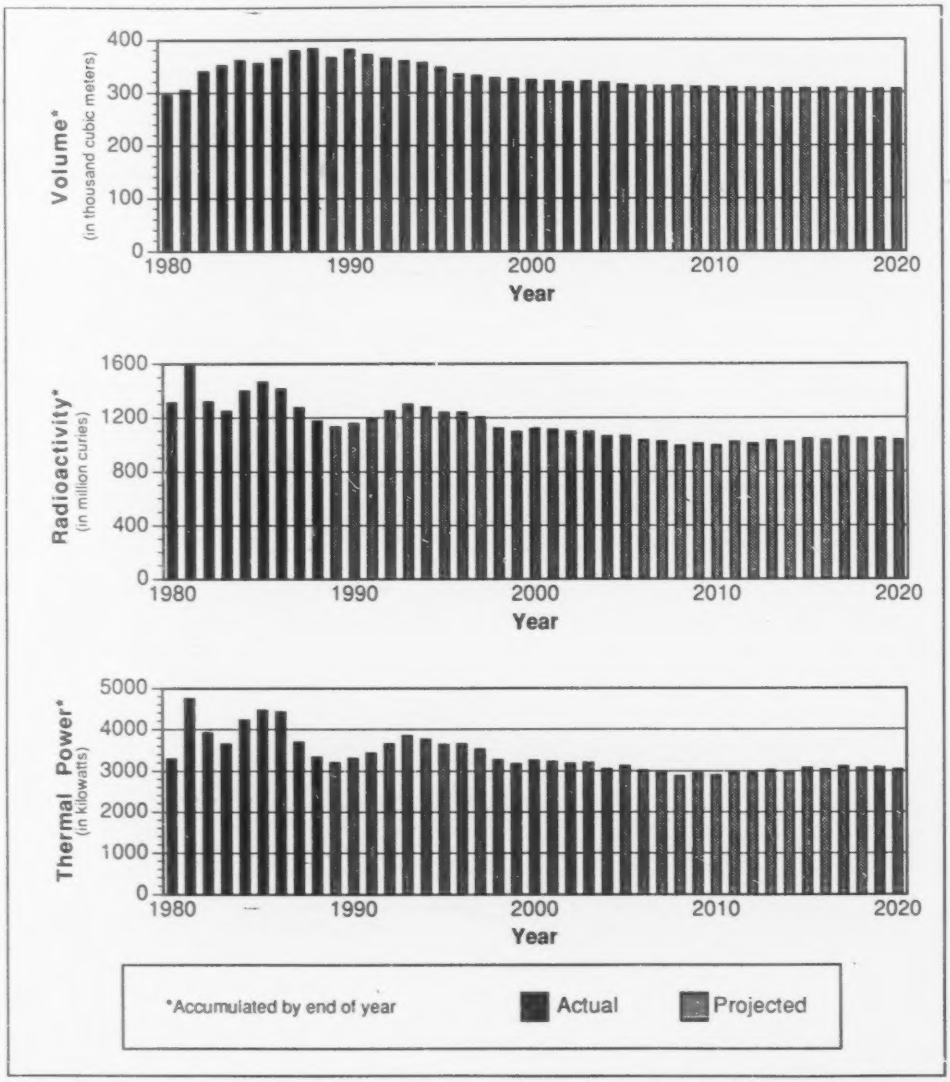
[15] The curie, a conventional unit of radioactivity, is equivalent to 37 billion disintegrations per second.

Figure 1-5—Total Volume, Radioactivity, and Thermal Power of High-Level Waste Stored in Tanks, Bins, and Capsules at Savannah River, Idaho, and Hanford (figures projected for 1989 to 2020)



SOURCE: Adapted from U.S. Department of Energy, "Integrated Data Base for 1989," DOE/RW-0006, November 1989.

were built to concentrate the waste. About 66 tanks are believed to have developed leaks. The contents of these tanks, therefore, are subject to more uncertainty than indicated in the IDB. The salt cake has the largest volume, whereas the sludge contains the highest radioactivity. Also at Hanford are 28 double-shell tanks containing 111 million curies of radioactivity, reported in the IDB as "slurry."

Idaho has 7,600 cubic meters of HLW liquid, more than twice the volume of calcine (3,400 cubic meters); however, the radioactivity of the calcine is 56.9 million curies, 5.6 times the radioactivity of the liquid (10.1 million curies). Calcination reportedly reduces the volume of HLW by a factor of eight (73). The volume reduction and radioactivity concentration that occur are indicated by the ratio of liquid-to-calcine volume per unit of radioactivity (12.6 to 1).

West Valley has three types of commercial waste: 1) 50 cubic meters (13,200 gallons) of acid liquid waste from reprocessing fuel containing thorium, located in one stainless steel tank; 2) alkaline waste consisting of 2,020 cubic meters (534,000 gallons) of liquid and 46 cubic meters (12,200 gallons) of sludge, all in one carbon steel tank; and 3) 13 cubic meters (3,430 gallons) of solid zeolite loaded with cesium-137 and stored underwater.

Inventories of defense HLW, both past (historical) and future (projected), are presented in tabular form in the IDB; they are plotted in figure 1-5. From the end of 1980 through 1988, the accumulated volume of HLW at the sites increased by 30 percent; radioactivity decreased by 10 percent, and thermal power (the rate at which heat is generated due to radioactive decay) increased by 1 percent. The fact that the radioactivity decreased while the volume increased can be explained in part by the decay of short-lived radionuclides. However, other factors may also be involved.

DOE is constantly revising its estimates of the volume and radioactivity of defense HLW as a result of new information that permits either better estimates of already existing HLW or reclassification of HLW to other categories such as transuranic (TRU) waste or low-level waste (LLW). For example, in the 1989 IDB, the volume and radioactivity of the Hanford strontium and cesium capsules were each reduced by roughly 10 percent from values in the 1988 report. The reason given was that over the years, a number of capsules had been dismantled and the contents used outside of Hanford; these will not be returned to Hanford (61). In addition, substantial changes were made to estimates of West Valley waste. Finally, estimates in the IDB include no error bounds to help the reader judge the accuracy of information. In the past, questions have arisen about the inventory of plutonium in the HLW tanks at Savannah River (26). Characterization of the contents of the single-shell tanks at Hanford could yield changes in estimates of their volume, radioactivity and composition.

Projections of HLW through the year 2020 are also included in figure 1-5. Projections are based on a scenario for weapons production dictated by national nuclear weapons material stockpile needs. They assume that three reactors at Savannah River will be restarted during 1989-90 (they were not) and will operate through the year 2000; after 2000 the three reactors will be replaced by one new production reactor. The projections include conversion of some liquid HLW to glass in the Defense Waste Processing Facility at Savannah River (and at West Valley) but not at Hanford or Idaho; however, elsewhere in the IDB, estimates are presented for the potential number of canisters holding immobilized waste at INEL and borosilicate glass waste at Hanford.

In figure 1-5, the cumulative volume, radioactivity, and thermal power of defense HLW stored in tanks, capsules, and bins, projected to the end of the year 2020, are somewhat lower (20 percent decrease in volume, 12 percent decrease in radioactivity, 9 percent decrease in thermal power) than those at the end of 1988. However, if projected glassified waste is added to the waste in tanks, bins, and capsules, the end-of-year projections for radioactivity and thermal power show an increase of 17.6 and 20.1 percent, respectively, whereas the volume decreases by 19.3 percent due to vitrification (see figure 1-6 for radioactivity projections). The volume decrease could be even greater by the end of 2020, the last year for which projections were made, if the Hanford vitrification and Idaho immobilization facilities come on-line as scheduled.

In terms of specific sites, a substantial increase in HLW volume and radioactivity (see figure 1-6) is expected for ICPP in the 21st century;[16] both are projected to grow to more than five times their 1988 values by the year 2020. As figure 1-6 indicates, most of the projected ICPP radioactivity is associated with the calcine. The projected radioactivity of HLW from accumulated production at Savannah River continues to increase, whereas it remains constant at Hanford. If the deep geologic repository is available by 2020, some of the glass attributed to Savannah River could be emplaced in, or in transit to, the repository.

Current and Potential Problems

Liquid Tank Storage: Soil and Groundwater Contamination; Tank Explosion

The three DOE weapons facilities with HLW—namely, Hanford, Idaho, and Savannah River—as well as the site at West Valley, all have a number of tanks on site that contain highly radioactive liquids and associated physical forms requiring constant vigilance. Many of these tanks can hold on the order

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[16] One of the functions of the ICPP is to recover highly-enriched uranium from spent naval reactor fuel for use in the "driver" fuel elements of the Savannah River production reactor (31).

Figure 1-6—Total Radioactivity of High-Level Waste in Storage by Site Through 2020
(figures projected for 1989 to 2020)

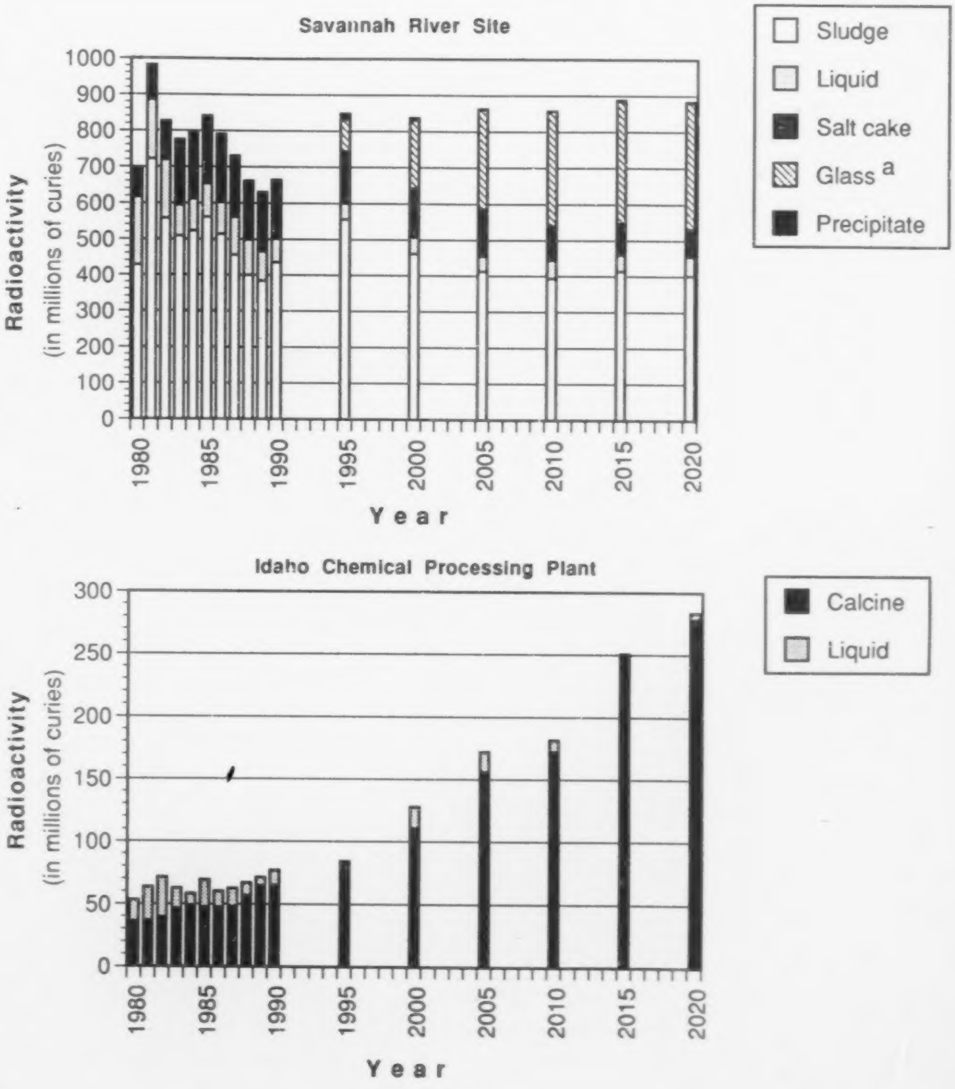
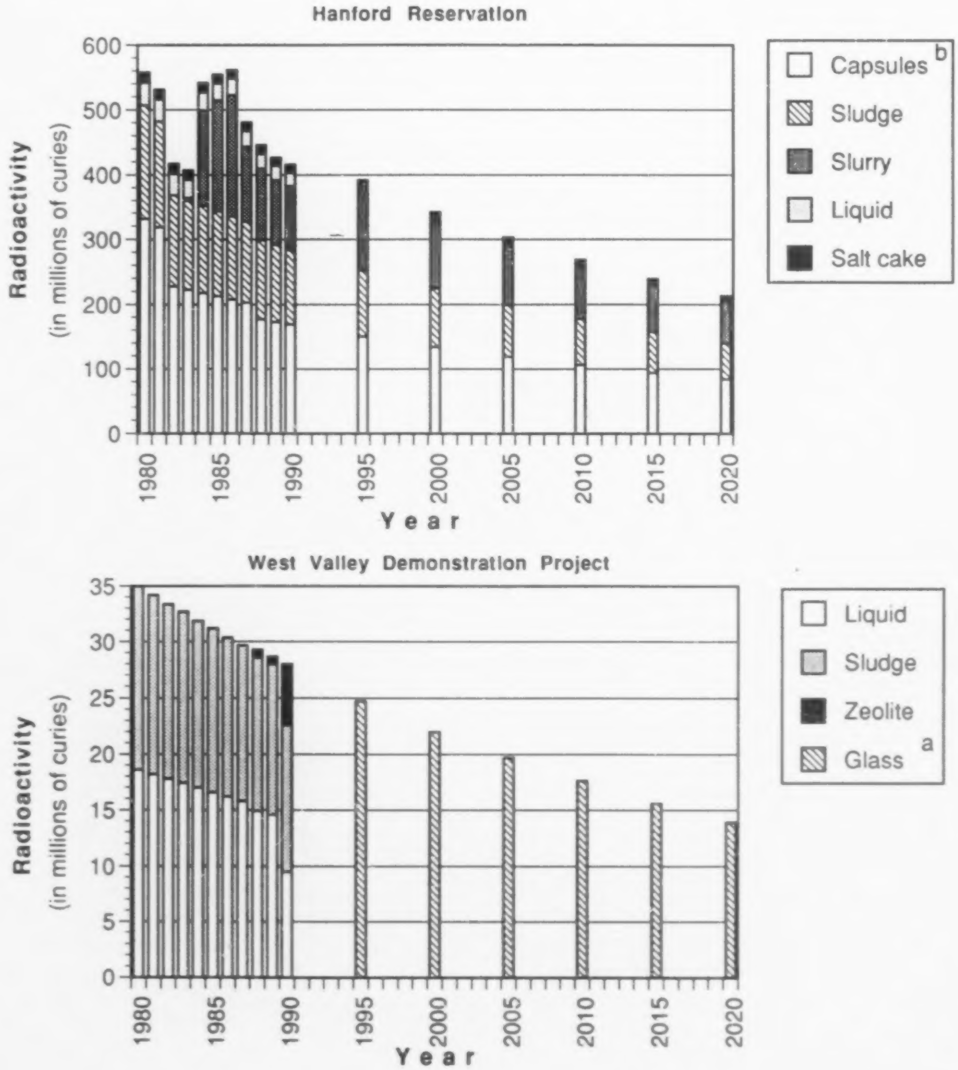


Figure 1-6—Total Radioactivity of High-Level Waste in Storage by Site Through 2020 (figures projected for 1989 to 2020)—Continued



NOTES: a. Glass may be in storage at the site, in transit to a repository, or in a repository.
b. Capsules contain either strontium fluoride or cesium chloride.

SOURCE: U.S. Department of Energy, "Integrated Data Base for 1989," DOE/RW-0006, November 1989.

of 1 million gallons (3,800 cubic meters) of waste. Tanks at Hanford and Savannah River have been the object of scrutiny by States, environmental groups, and local citizens concerned with leakage and subsequent environmental contamination, and with the possibility of explosion. Tanks at Idaho, although used mostly for short-term storage prior to calcining the waste, are in concrete containment vaults that do not meet either current design basis earthquake standards or present-day RCRA secondary containment rules (53).

Hanford has 149 single-shell tanks and 28 double-shell tanks, both made of carbon steel as opposed to the more expensive stainless steel. Because of the highly acidic nature of liquid waste leaving the Plutonium Production and Extraction reprocessing plant, the waste must be neutralized to prevent reaction with the tank walls. The neutralization step precipitates sludge at the bottom of the tanks and complicates subsequent transfer. At Hanford, the single-shell tanks were built before the double-shell tanks, when there was less concern with environmental and health effects than exists now; the first tank was put in operation in 1944 (see table 1-1 for chronology).

According to a 1989 General Accounting Office (GAO) report, DOE officials estimate that from 1959 through 1988, definite or possible leaks had occurred in 66 of the 149 single-shell tanks (5 leaking tanks were identified in 1988), releasing about 750,000 gallons of HLW as estimated by contractor personnel (42). Earlier, liquid waste from some single-shell tanks was deliberately released to cribs from which waste percolated into the soil as part of the disposal process.[17] The first indication of a potential leak occurred in 1956; no new liquid has been added to the single-shell tanks since 1980 (see table 1).

The environmental and health impacts due to the movement of liquid waste from single-shell tanks into the soil are not well established. There is no unanimity about pathways through which the radioactive and hazardous substances travel or their ultimate fate. The GAO summarizes the situation as follows (43):

> DOE officials have stated that the environmental impact of the single shell tank leaks will be low or non-existent and have cited several studies as a basis for their assessment. However, we believe the studies do not provide conclusive evidence about the degree of environmental impact attributable to tank leaks. Some studies indicated there would be limited environmental impact, but they did not analyze the impact of several mobile contaminants on Hanford's groundwater. One study predicted groundwater contamination would exceed safe drinking water standards but did not project the impact on the Columbia River.

Information in a recent report by the Hanford Education Action League (HEAL) supports the case that groundwater contamination from a variety of sources on the Hanford reservation reached the Columbia River much more rapidly than was previously believed due to geological channels under the Hanford site or to the presence of organic chemicals that speed migration (11). DOE has yet to complete a comprehensive study of subsurface contamination at Hanford.

Since 1973, DOE's strategy for limiting single-shell tank leaks has been to remove the liquid and seal the tanks to prevent penetration by liquids such as rainwater. A large volume of liquid has been removed by evaporation or by pumping to double-shell tanks. However, according to GAO, pumping has been delayed in part because of space limitations as a result of tank space being allocated to ongoing production programs. GAO recommended that DOE develop specific plans to place an interim ground surface material over the tank farms to slow water drainage through the soil (44).

In a 1987 DOE final EIS, the preferred alternative for dealing with the Hanford single-shell tank waste was to study the matter further and defer decision (59); this alternative was singled out because the need for action was believed to be less immediate than in other tasks to be performed, given that most of the liquid had already been removed from the tanks and that the remaining sludge and semisolids had limited mobility. The Hanford Federal Facility Agreement and Consent Order and the associated Action Plan of May 1989, entered into by DOE, EPA, and the State of Washington's Department of Ecology, known as the tri-party agreement, codify deferral of disposal of single-shell tank waste (71), as proposed in the Hanford EIS. According to the tri-party agreement, a full-scale tank waste farm retrieval demonstration is not scheduled until the year 2004, with complete closure of all 149 tanks by 2018 (71). At present, effort appears to be focused on

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[17] Personal communication during visit to Hanford, November 1989. See also S.P. Cowan, op. cit, footnote 11.

Table 1-1—Chronology of Major Events in the History of Single-Shell Tanks at Hanford

1944	First single-shell tank went into service.
1956	First indication is obtained of a potential leak.
1959	First leak occurred.
1964	Construction was completed on last group of single-shell tanks.
1966	Last of single-shell tanks went into service.
	Total volume of waste in single-shell tanks reached ca. 77 million gallons.
1968	Construction of first double-shell tanks began.
1970	Groundwater monitoring well was drilled. Highly radioactive contaminants leaking from single-shell tanks were later detected in groundwater. According to DOE, migration to groundwater most likely occurred during drilling of well but might have been a natural progression through the soil.
1971	Double-shell tanks became operational.
1972	Pumping program was begun to transfer liquid from single to double-shell tanks.
1973	Largest single-shell leak occurred--an estimated 115,000 gallons.
1980	DOE stopped placing waste in single-shell tanks.
	Liquid waste levels in single-shell tanks were reduced to no more than 1 foot above solid waste.
	Plans were adopted to transfer the remaining 8.5 million gallons of single-shell tank waste that could be feasibly pumped into double-shell tanks by 1985.
1985	Planned pumping schedule was not followed, and scheduled pumping of single-shell tanks ended. Since August 1985, DOE had pumped liquids only from tanks it assumed had leaked, with the exception of about 16,000 gallons pumped from one tank in 1986.
1988	Five tanks were added to the list of assumed leakers.
1989	DOE, EPA, and Washington State signed an agreement in which DOE agreed to pump most of the remaining 5.3 million gallons of pumpable liquid waste from the single-shell tanks by the end of FY 1995. However, in accordance with the agreement, two tanks that may be susceptible to excessive heating and require supplement cooling are scheduled to be pumped by the end of FY 1996.

SOURCE: U.S.Congress, General Accounting Office, "Nuclear Waste: DOE Management of Single-Shell Tanks at Hanford, Washington," Report GAORECD-89-157, July 1989.

characterizing tank wastes. A National Academy of Sciences panel advises DOE on a continuing basis on single-shell tank waste. At a December 1989 meeting, panel members urged DOE and its contractors to conduct a systems analysis of alternative approaches for treating and disposing of tank wastes.[18]

High-level waste in Hanford double-shell tanks is to be vitrified, starting in 1999, at the Hanford Waste Vitrification Facility (HWVF); a $550-million contract for construction of the HWVF was awarded in December 1989 to United Engineers and Contractors (72). Waste from these tanks is to be pretreated prior to vitrification. Because there are only 28 of these tanks and they are very expensive to build, DOE is concerned with managing the waste in them to conserve storage space. Pretreatment serves to separate a portion of the original liquid HLW so that it can be treated as low-level waste (i.e., grouted), and to free up tank space for additional HLW. Although double-shell tanks appear to be a technological advance over single-shell tanks, the form (sludge and supernatant liquid) and intense radioactivity of their contents are given priority in the major milestones for disposal of tank waste in the tri-party agreement, which include initiation of pretreatment of double-shell tank waste in B Plant by October 1993 and initiation of HWVP operations by December 1999 (71). In February 1991, DOE proposed a two-year delay in the startup of the HWVP; startup of B-Plant may be delayed until the end of 1997.[19]

A potential problem that has received widespread public attention only recently is the possibility of explosions in HLW tanks. In the 1950s, potassium ferrocyanide was added to the single-shell tanks at Hanford to precipitate radioactive cesium and strontium so that liquid could be pumped from the tanks to create room for more high-level liquid waste. Ferrocyanide, mixed with nitrites and nitrates in the tanks, can be explosive if certain temperatures are exceeded. A "worst case" scenario, considered in a 1984 Battelle Northwest Laboratories report, indicates that the energy release in such an explosion could be equivalent to 36 tons of TNT (7). Concern about tank explosion has been heightened by reports of a chemical explosion in a nuclear waste tank at Kyshtym in the Soviet Union, that occurred in 1957 and resulted in the evacuation of 10,000 people and reportedly released 20 million curies of radioactive materials (15).

DOE's position regarding the explosion hazards in the Hanford tanks has been that there is no immediate risk because temperatures in the tanks are well below those at which ferrocyanide explosions might occur.[20] However, concerns have been expressed about uncertainties in characterization of the waste and about possible hazard if the waste was mechanically or thermally disturbed (e.g., through in situ vitrification, vitrification in the Hanford Waste Processing Facility, or cutting into the salt cake). Although DOE is studying the situation, further research has been recommended to learn whether any other materials present in the tanks represent an explosion hazard under certain conditions.[21]

In March 1990, DOE revealed that hydrogen gas has been building up in 20 of the HLW storage tanks at Hanford (19). Hydrogen arises from the decomposition of organic materials placed in the tanks and from radiolysis of water. Although Michael Lawrence, the DOE Hanford facility manager at the time, is quoted as stating that DOE believes the danger of an explosion is low and the potential for radioactive release even lower, according to Lawrence, "the worst case is any explosion that could cause the dome to collapse and send the contents up to the air . . .. I can't sit here and say it's not going to happen" (19). John Conway, chairman of the Defense Nuclear Facilities Safety Board, stated after a briefing on the Hanford tank situation in March 1990 that the board considers the danger of a hydrogen explosion potentially more serious than a ferrocyanide explosion (4). However, a subsequent statement in April 1990 quoted Conway as saying, "We don't believe there is any kind of risk to the public" (18).

In a July 23, 1990 letter to the Secretary of Energy, DOE's Advisory Committee on Nuclear Facility Safety (ACNFS) stated that: "The (high level) waste tanks are a serious problem. The possibility of an explosion of an unstable chemical (such as ferrocyanide) or a flammable gas must be taken seriously because of the magnitude of the radioactive inventory available for dispersal."[22] Although the ACNFS "found nothing to indicate that emergency action was required,"[23] serious concerns were presented: 1) apparent lack of concern on the part of the operating staff for the tanks about the hazard; 2) apparent lack of attention by top DOE management and the contractor about achieving higher levels of tank safety; 3) an attitude at the DOE Richland Operations Office that because the tri-party agreement exists, waste issues are being efficiently resolved, even though the agreement postpones major decisions on waste handling and risks from operations. The apparent neglect of several factors that may call into question Hanford's belief that there is "no deflagration or detonation hazard because of the differences between temperatures measured in the tanks and temperatures of the onset of reactions observed in the laboratory tests." They go on to state that:

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[18] Discussion at meeting of National Academy of Sciences Panel on Hanford Single-Shell Tanks, Dec. 6, 1989.

[19] "Secretary Delays Construction of Hanford Waste Vitrification Plant," *Weapons Complex Monitor*, Feb. 25, 1991, p. 12.

[20] FD Personal communication during visit to Hanford, November 1989.

[21] Comment by panelist at meeting of National Academy of Sciences on Hanford Single-Shell Tanks, Dec. 6, 1989.

> The Hanford tanks present a serious situation, if not an imminent hazard . . . much more effort must go into determining what is in the tanks, what is happening in the tanks, and what are the possible reactions that can occur. . . .[24]
>
> Uncertainty surrounding the possibility of conflagration and explosion in the waste tanks does need to be resolved as rapidly as possible. The material presented to us at Hanford was weak, but did include the suggestion that the probability of conflagration may be low and that, even if it were to occur, the energy release might not rupture the tanks. However, the available information, the analyses and the experiments that have been done, leave wide margins of uncertainty.

Until this uncertainty is resolved, the ACNFS recommends establishing continuous monitoring and action plans for coping with the event of excessive pressures or temperatures, or for a release.[25]

A significant airing of the tank explosion issue took place at a hearing on "Accident and Explosion Risks at Department of Energy High-Level Radioactive Waste Facilities" by the Senate Committee on Governmental Affairs on July 31, 1990. One of the witnesses, the DOE Director of the Office of Environmental Restoration and Waste Management, Leo Duffy, indicated that additional steps being taken by DOE include formation of a Headquarters Tank Advisory Panel to review waste tank technical issues at all DOE sites, and formation of a Senior Chemists Panel for Hanford to review waste chemical reactions.[26] Two additional statements by Duffy shed light on DOE's ambivalent attitudes toward external oversight as well as the apparent seriousness with which they now view the tank explosion issue:

> All the oversight in the world will not do the job that we must do ourselves. We have had independent reviews of various pieces to this puzzle—first, the presence of ferrocyanide in the tanks, followed by the discovery of hydrogen gas generation, followed then by the realization that nitrous oxide was present in the tanks as well—all of which indicates a material weakness on the part of DOE and its contractors to understand the fundamental chemistry present in its HLW tanks.
>
> As slow as we may have been to uncover these events and then link them together, our 'discovery' was not made with the help of the technical safety appraisals, which failed also to identify the potential hazards posed by the presence of these chemicals and failed to add to our understanding of the potential seriousness of the chemical reactions that were taking place.[27]
>
> . . . in my opinion, the issue of accident potential in the high-level waste tanks would not have surfaced without your (Senator John Glenn) question on ferrocyanide in the single-shell tanks. This question resulted in the subsequent examination of hydrogen generation, the presence of nitrous oxide and our need to understand tank chemistry issues, and the general lack of discipline and follow-up needed to resolve long-standing technical issues in the Hanford tank farm. It resulted also in the evolution of methods used in Technical Safety Appraisals, safety audits, and Tiger Team Assessments. I want to express to the Chair my appreciation to this Commit-

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[22] Letter from John F. Ahearne, Chairman, Advisory Committee on Nuclear Facility Safety, to the U.S. Department of Energy, to James D. Watkins, Secretary of Energy, July 23, 1990, p. 4.

[23] Ibid.

[24] Ibid., pp. 5-6.

[25] Ibid., pp. 6-7.

[26] Statement by Leo Duffy, Director, DOE Office of Environmental Restoration and Waste Management at hearing on "Accident and Explosion Risks at Department of Energy High-Level Radioactive Waste Facilities," U.S. Senate Committee on Governmental Affairs, July 31, 1990, p. 13.

[27] Ibid., pp. 15-16.

tee and to its staff for helping us to begin resolving these potentially serious issues.[28]

In October 1990, the Defense Nuclear Facilities Safety Board (DNFSB), which was established by Congress to provide oversight of DOE activities, indicated in a letter to DOE Secretary Watkins that DOE and Westinghouse Hanford Co. were not moving fast enough to implement safety measures at the Hanford tanks.[29] These measures include installing new instrumentation, accelerating tank sampling, and developing plans for dealing with possible explosions.

The tank situation at Savannah River has received less media attention than that at Hanford. Savannah River has the largest amount of radioactivity of all sites in the form of HLW. According to the FY 1989 Savannah River Waste Management Plan, there are 51 large, subsurface tanks for storing and processing aqueous HLW (64). All are made of carbon steel and there are four different designs; none of the tanks appears to be equivalent to the Hanford single-shell tank. According to DOE, some leakage of tanks has occurred along with rusting of tank walls (64). A program to transfer waste from older tanks to newer, Type III tanks, which are believed to have good near-term integrity, is scheduled to be completed through 1995. There are 27 of these double-shell Type III tanks (64).

Problems with the HLW tanks at Savannah River figured prominently in a 1986 report (26) by the Environmental Policy Institute (EPI), namely concern about: 1) contamination of the shallow aquifers beneath Savannah River; 2) possibility of tank explosions; 3) potential threat of an earthquake, which the tanks were not designed to withstand (in an area that had a large earthquake in 1886); and 4) excessive radiation exposure of personnel working around the tanks or dealing with certain aspects of the DWPF vitrification plant when it begins operation (26). The highly critical tone of the EPI assessment contrasts with DOE descriptions of Savannah River HLW operations.

In EPI's 1987 reply to Du Pont's response to its Savannah River critique, the report states that the buildup of organic vapors in tanks has a larger likelihood of occurring than does buildup of hydrogen (27). Furthermore, EPI finds Du Pont's estimates of the probability of a tank explosion to be considerably lower than its own (27). In October 1990 the condition of the tanks at Savannah River and the possibility of explosions and fires were being studied by a variety of groups including the Advisory Committee on Nuclear Facility Safety.

According to the 1989 Five-Year Plan, INEL's HLW tanks, although stainless steel and still sound, are 35 years old and their concrete containment vaults do not meet either current earthquake standards or RCRA secondary containment rules. As a result, DOE plans in FY 1991 to design and eventually construct four 500,000-gallon tanks to replace five of the eleven 300,000-gallon tanks currently storing HLW at the Idaho facility (53); the new tanks are to be put into operation by FY 1997 (56). This appears to be the only facility in which new HLW tank construction is planned. If shutdown of the calcination facility continued for a long time, the liquid tank storage capacity required would increase.

In summary, HLW storage tanks represent potential sources of radioactive releases to the soil—and, hence, to water under the site and eventually off-site—or of more widespread release by explosion or natural disaster such as an earthquake. Many tanks were not designed for long-term storage, and the use of carbon steel necessitated neutralizing the waste, which has resulted in complex mixtures of liquid, sludge, and salt cake that are difficult to move and represent a potential hazard to those involved in sampling tank contents or in other operations. Ironically, new tanks are to be built at the one location of three in the Weapons Complex that has the smallest amount of HLW, where stainless steel rather than carbon steel tanks are present, and where calcining is used to solidify HLW, namely, Idaho. By contrast, at Hanford, no decision seems near on how to dispose of single-shell tank waste. A lot is riding on the success of the vitrification plants at Savannah River and Hanford to reduce the risk posed by high-level tank wastes.

Reprocessing Plants: PUREX

The high-level radioactive waste in interim storage as liquid slurry or calcine is generated by the reprocessing of spent fuel and irradiated targets. Before reprocessing, most of the radioactivity is associated with and contained in the confines of the solid spent fuel and targets. To recover plutonium

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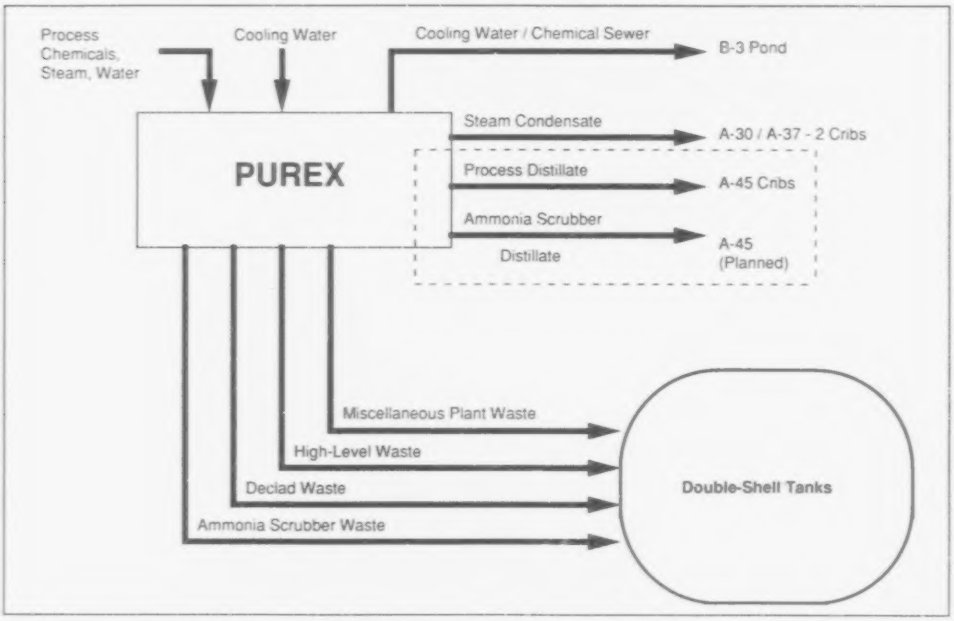
[28] Ibid., pp. 16-17.

[29] Geranios, N.K., "Federal Board Finds Tank Plans Inadequate," Associated Press News Release, Oct. 17, 1990.

Figure 1-7—Chemical Processing of PUREX Liquid Effluents


Process Chemicals, Steam, Water
Cooling Water
Cooling Water / Chemical Sewer
B-3 Pond
PUREX
Steam Condensate
A-30 / A-37 - 2 Cribs
Process Distillate
A-45 Cribs
Ammonia Scrubber Distillate
A-45 (Planned)
Miscellaneous Plant Waste
High-Level Waste
Declad Waste
Ammonia Scrubber Waste
Double-Shell Tanks

SOURCE: Westinghouse Hanford Co., November 1989.

for weapons use, these solids must be chopped up, dissolved, and processed with both organic and aqueous solvents. The net result is a huge increase in the volume of radioactive waste. Figure 1-7 illustrates some of the liquid streams from the Plutonium and Uranium Extraction (PUREX) plant at Hanford; the PUREX process with appropriate modifications has generally been adopted as the standard for reprocessing nuclear fuel, both in the United States and worldwide.

Some indication of the potential environmental impact of the PUREX plant is given by the following (40):

> Reprocessing plants like PUREX and its predecessors, which recover plutonium from irradiated uranium, have been responsible for some of the worst environmental contamination at Hanford because they generate huge volumes of toxic chemical and radioactive wastes. The process that produces one kilogram of plutonium at PUREX also produces over 340 gallons of liquid high-level radioactive wastes mixed with hazardous chemicals, more than 55,000 gallons of low- to intermediate-level radioactive wastes discharged to cribs, and over 2.5 million gallons of cooling waters disposed to ponds.

Some advocate reprocessing fuel to recover and recycle transuranic radionuclides as a way of reducing the radioactive waste disposal burden. According to this approach, with recycling, long-lived transuranics such as plutonium-239 are contained within the reactor, reprocessing plant, and fuel fabrication plant or their immediate vicinity. Therefore, the waste to be disposed of contains fewer long-lived radioisotopes. However, reprocessing usually expands the volume of waste to be dealt with, and long-lived radionuclides are not totally eliminated by transmutation in the reactor.

In December 1989, the PUREX facility at Hanford was shut down in "mid-campaign,"[30] that is, with highly radioactive materials dispersed throughout the system. Some 20 metric tons of material was present in the dissolvers and 70 metric tons elsewhere in the system.[31] PUREX, which is more than 30 years old, went through a long shutdown period in the 1970s and early 1980s (9). In November 1989, Westinghouse and DOE officials at Hanford were hoping to perform a "stabilization" run on the system (i.e., operating the system to clean out material dispersed through it) as soon as possible, followed by a campaign to reprocess the 2,100 metric tons of fuel, including 350 metric tons of weapons-grade material awaiting reprocessing.[32] Obstacles to restart included environmental regulation, concerned citizens groups, and the age and condition of the facility.

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[30] The term "campaign," as used by DOE, means operation of the facility to process one batch of fuel from start to finish.

[31] Personal communication during visit to Hanford, November 1989.

Concerns about PUREX reported in the media or raised by environmental and citizen groups include the following:

1. Some reports claim that radioactive liquid effluent streams from the plant continue to be discharged into the soil, even though the fate of radioactive and hazardous materials in these discharges is not well known. The following material is from Associated Press (17): "According to the Hanford Education Action League, PUREX discharges up to 9,000 gallons of liquid per day (into the soil) when operating; even in a standby (shutdown) condition, it discharges 4,000 to 5,000 gallons per day into the soil. A DOE spokesman maintains that continued liquid flow is necessary during 'idle' for safety reasons. Although PUREX is only one source of liquid discharges at Hanford, it is the 'biggest single liquid waste generator.' " Again, according to the Hanford Education Action League, of the 33 liquid waste streams identified at Hanford, the 19 most radioactive must be stopped, stored, or treated by June 1995 (in compliance with the tri-party agreement). A Hanford report estimates the cost to prevent dumping of liquid wastes into the soil to be $244 million."

   An article in October 1989 (40) reported that after PUREX was built in 1956, it took only 7 years for a radioactive tritium plume from its operations to reach the Columbia River, some 9 miles away; that plume results in about 4,000 curies of tritium entering the river annually, according to DOE-contractor water monitoring reports.[33] Originally, it was expected to take 175 to 180 years for contaminated groundwater to travel to the Columbia River; the fact that movement is an order of magnitude more rapid is perhaps due to channeling effects under the Hanford site or to the presence of organic chemicals that speed migration.[34]
2. An Associated Press article in December 1989 stated that shutdown of the plant in 1989, during a campaign, necessitated a stabilization run to blow out material that had settled in pipes and other equipment. A concern was that radioactive and hazardous liquids might be discharged if the plant were started up in this condition, with materials distributed throughout the system, especially if any equipment were to fail. Because of the age of the plant, equipment failure has been common in recent years.[35] In December 1989, DOE and Westinghouse-Hanford began a "phased restart to stabilize chemicals" (75).
3. The ACNFS has expressed concern about the high turnover of workers and management at PUREX that could lead to a potential safety issue when the plant is restarted.[36]
4. There is also some concern that DOE and Westinghouse-Hanford have not always provided information on occurrences at the plant in a timely and accurate fashion.
5. Finally, some have stressed a number of regulatory issues that center on hazardous waste streams in the PUREX facility, such as the use, treatment, and disposal of "listed wastes" (e.g., acetone, *n*-butyl alcohol, xylene, and toluene). These issues are important in considering the restart of PUREX.

Support for the restart of PUREX offered by DOE and DOE-contractor personnel at an OTA meeting at Hanford in November 1989 was based on the following: Spent fuel from the N reactor awaiting reprocessing is being held in water basins at K plant, just one-quarter mile from the Columbia River. These basins have leaked in the past. The metallic fuel elements sustained some mechanical damage in being unloaded from the N reactor into storage pools; some 6 to 10 percent of the fuel is estimated to be in a failed condition.[37] In this condition, radionuclides can be released to the water basins which, if they were to leak again, could cause groundwater and river contamination.

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[32] Ibid.

[33] The DOE contractor report cited is Pacific Northwest Laboratory, "Environmental Monitoring at Hanford for 1984," PNL-540-1, May 1985.

[34] Tritium is not produced deliberately by irradiation of lithium targets in the Hanford reactors. However, it is produced by fission in the fuel. Some tritium is released as a gas in the dissolution process, whereas the remainder follows the aqueous reprocessing stream and is released to the environment as tritiated water vapor or liquid. See M. Benedict, T.H. Pigford, and H.W. Levi, *Nuclear Chemical Engineering*, 2d ed. (New York, NY: McGraw-Hill, 1981), p. 357.

[35] For example, a concentrator failure led to an extended outage; it was one of several factors involved in the suspension of PUREX operations during 1989. Source: Viewgraph from briefing by D.H. Shuford, "PUREX Status, Plans and Issues," Nov. 17, 1989. In addition, the *New York Times*, on Dec. 16, 1989, reported that on Dec. 3, 1989, an unexplained chemical reaction in a pipe of the shutdown PUREX plant "ruptured a gasket and sprayed acid into an area sometimes occupied by workers."

[36] J.F. Ahearne, U.S. Department of Energy Advisory Committee on Nuclear Facility Safety, letter to James D. Watkins, Secretary of Energy, July 23, 1990.

In March 1990, DOE provided the following information concerning the PUREX stabilization run and proposed restart:[38]

> PUREX was restarted on December 17, 1989, to complete a processing run that was interrupted on December 7, 1988. The processing run was successfully completed March 1, 1990. Only minor operational/equipment problems were encountered during the run. PUREX is now scheduled for an extended outage of approximately one year to prepare for the processing of the irradiated N reactor fuel now in storage. Activities scheduled during the outage include an inventory of special nuclear materials, maintenance and repairs, and the construction of waste disposal facilities. An Environmental Analysis (EA) will be issued in March, 1990. The EA will determine whether the previous environmental impact statement for PUREX needs to be updated.

A July 1990 analysis of whether or not to restart PUREX was prepared by the Institute for Energy and Environmental Research (IEER) for the Hanford Education Action League (HEAL).[39] In a subsequent article, the situation is described as follows:[40]

> The environmental problem posed by the fuel is real enough. About 3-7 percent of the N-reactor fuel is damaged and is being corroded by contact with water. The spent fuel in K-West is sealed inside water-filled containers which contain the radioactivity, but the fuel elements in K-East are stored in open cans, and the water in the basin is highly contaminated. Workers do not enter the pool area without special radiation protection equipment. The pool itself leaked before it was repaired in 1980, and Westinghouse estimates that some 15 million gallons of water contaminated the surrounding environment with up to 2,500 curies of strontium 90 and cesium 137.

The IEER-HEAL report's preliminary short-term recommendations were: 1) PUREX should not restart because the hazards of greatest consequence appear to be connected with reprocessing as opposed to other N-fuel management options; 2) to minimize the risks of continued storage of N-fuel in the K-basins, exposed N-fuel should be encapsulated as soon as possible; and 3) preliminary design of dry storage facilities for interim management of N-fuel should also begin as soon as possible.[41]

The decision as to whether or not to restart PUREX is a significant one. It depends on factors such as the need for additional plutonium for the U.S. weapons stockpile and the desirability of keeping some form of production mission for the Hanford site. In October 1990, DOE Secretary Watkins announced his decision not to restart the PUREX plant for at least 2 years.[42] During that 2-year period, a study will be conducted of environmental issues associated with PUREX. Although the option of restart after 2 years still seems to be left open, some observers interpret the decision as indicating that PUREX will never again operate.[43]

Major chemical processing-reprocessing facilities also exist at Savannah River and INEL. Late in 1989, the ICPP, which processes fuel for naval reactors, was put on "temporary standby" because of concerns about underground piping leading to storage tanks. The piping is single-walled, and RCRA requires secondary containment such as double-walled piping. In addition, the New Waste Calcination Facility (NWCF) at the ICPP had not operated since October 1988. Calcination was to have been resumed, after completion of a "dissolution campaign," on July 9, 1989, but was postponed pending correction of piping deficiencies.[44] Other postponements followed.[45] [46] A December 1990 Associated Press news release indicated that startup of the NWCF was imminent and that the reprocessor might be restarted in January 1991. In addition, no Savannah River site fuel has been reprocessed since 1988, although some off-site fuel continued to be processed in 1990. Although INEL and Savannah River reprocessing facilities seem to generate less public concern than the PUREX plant at Hanford, presumably they all use the same basic process with some differences in details and could be subject to some of the same problems.

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[37] Information for this paragraph was obtained from DOE and DOE-contractor personnel during a trip to Hanford in November 1989.

[38] S.P. Cowan, op. cit., footnote 1.

[39] S. Saleska and A. Makhijani, "To Reprocess or Not To Reprocess: The PUREX Question, A Preliminary Assessment of Alternatives for the Management of N-Reactor Irradiated Fuel at the U.S. Department of Energy's Hanford Nuclear Weapons Production Facility," Report prepared for Hanford Education Action League, July 1990.

[40] S. Saleska and A. Makhijani, "Hanford Cleanup: Explosive Solution," *Bulletin of the Atomic Scientists*, vol. 46, No. 8, Oct. 1990, p. 20.

[41] Ibid.

[42] N.K. Geranios, "Plutonium Processing Plant Won't Reopen, Energy Secretary Says," *Associated Press News Release*, Oct. 17, 1990.

[43] R.J. Smith, "DOE Drops Plan To Resume Making Plutonium for Bombs," *Washington Post*, Oct. 17, 1990, p. A2.

Although they have not arisen in recent years, two other concerns may be relevant to concerns about future waste management effectiveness:

First, given the importance of plutonium and uranium-235 as weapons-grade materials, it is essential that they be carefully accounted for by material balances. Past uncertainties about the amount of plutonium and other materials in the underground HLW storage tanks or the amount discharged into the soil indicate that careful accounting has not always been the case. It may be useful to audit the current materials accounting system.

Second, U.S. experience and practice in fuel reprocessing may not be keeping up with the state of the art in several European countries and Japan since they are pursuing commercial reprocessing whereas the United States is not. In planning the modernization of weapons facilities, including minimizing waste generation and environmental impact, non-U.S. input could prove valuable and should be sought, consonant with U.S. security requirements.

Contamination From Strontium and Cesium Capsules

In 1968, the "B" Plant at Hanford was converted to remove radioisotopes of cesium and strontium from PUREX acid waste and from supernatant liquids in HLW tanks. Through 1985, these radioisotopes were solidified as strontium-fluoride and cesium chloride and doubly encapsulated (10). According to the 1989 Integrated Data Base, 1,349 cesium capsules and 597 strontium capsules are stored in a water basin, pending additional packaging and disposal in a repository (61). The half-lives of beta-emitting strontium-90 and beta- and gamma-emitting cesium-137 are 28 and 30 years, respectively; thus disposal for several hundred years rather than tens of thousands of years should suffice to reduce the radioactivity to acceptable levels.

IDB 1989 estimates of the volume of strontium and cesium capsules stored at Hanford were reduced by roughly 10 percent over the previous year "to reflect the fact that over the years 43 strontium capsules and 227 cesium capsules have been dismantled and put to beneficial use outside Hanford. These radionuclides will not be returned to Hanford" (61). Even though no problems have been reported about the capsules stored at Hanford, some concerns have been raised about those that have been shipped elsewhere. For example, an *Atlanta Journal* article states that (39): Some 252 cesium capsules had been used by Radiation Sterilizers, Inc. (RSI) to sterilize medical supplies. That operation has been shut down since June 1988 when a leak was detected in one of the stainless steel capsules. Some 159 of the capsules were still in the RSI building. Removal of the capsules to Hanford was halted when cracks were found in nine of the lead-lined containers used to ship the capsules. DOE is reported to have assumed responsibility for removal of all capsules to Hanford, in contrast to the impression given in the IDB. That removal involves transporting the capsules from DeKalb County, Georgia to Richland, Washington.

The Atlanta newspaper account emphasizes that the situation at RSI poses no public danger. It highlights the tension that has arisen between officials of the Georgia Department of Natural Resources and DOE officials at Hanford. It also contains the following statement: "DOE officials now acknowledge that the cesium-filled capsules should never have been used for commercial purposes" (39). An October 1988 Office of Technology Assessment (OTA) report concludes that theft and improper handling of sealed radiation sources have been responsible for 14 deaths and 4 major accidents in foreign countries over the last 25 years (47). One of these accidents, which occurred in Goiania, Brazil in 1987 and resulted in four deaths plus widespread contamination, has been called the second worst radiation accident in history (37). The situation in Goiania was caused by the removal of a stainless steel cylinder containing 1,400 curies of cesium-137 from a cancer therapy machine in an abandoned clinic (37).

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[44] Information for this paragraph was compiled from M.L. Wald, "Two Nuclear Plants Closed: Pipes Held Substandard," *The New York Times*, Nov. 4, 1989; and "INEL Puts Chemical Reprocessing Plant on 'Standby' to Make RCRA Changes," *Report on Nuclear Defense Plant Wastes*, Nov. 10, 1989, p. 204.

[45] S.P. Cowan, op. cit., footnote 11.

[46] As reported by DOE in June 1990, the ICPP, which includes the NWCF, was not operating while the plant underwent an environmental compliance assessment. A restart date of August-September 1990 was projected. Meanwhile, no fuel dissolution, reprocessing, or calcination of resulting waste was going on at ICPP. Source: S.P. Cowan, U.S. Department of Energy, personal communication to R.P. Morgan, June 5, 1990.

Given the situation that has arisen at RSI and concerns about more serious problems, it appears that the strontium and cesium capsules at Hanford will probably not be destined for future beneficial uses but will remain as waste destined for geologic disposal. In 1990, DOE asserts that all capsules are accounted for. Capsules which are not disassembled for use as material sources are to be returned for storage pending eventual treatment prior to disposal in a geologic repository.[47]

In response to a follow-on question by OTA, DOE indicated that some strontium and cesium capsules were sent to the Office of Isotope Sales operated by Oak Ridge National Laboratory (ORNL). These capsules were disassembled and the isotopes sold to commercial ventures. Once sold, "regulating responsibility and oversight is transferred to the Nuclear Regulatory Commission. Disposition and accountability are then no longer the responsibility of DOE."[48]

Delays and Uncertainties About Vitrification

In November 1989, GAO completed a study of DOE's program to prepare HLW for final disposal (45). GAO found that the Defense Waste Processing Facility for vitrifying HLW at Savannah River was 2 years behind schedule, and the West Valley Demonstration Project, also for vitrifying HLW, was 8 years behind schedule. The DWPF at Savannah River is now scheduled to begin operation in FY 1992.[49] The DWPF has been under construction for several years and has benefited from a series of tests on smaller scale equipment as well as full-scale operation of similar technology in Europe. Even so, the DWPF is a very complex facility of the type that usually encounters startup problems. Further delays and uncertainties may be expected at DWPF. Delays have also been encountered at West Valley. Although it has been possible to utilize some existing facilities left over from the time of West Valley's fuel reprocessing operations, decontamination added to the burden, as opposed to the entirely new building at Savannah River (70). It has also suffered continually from budget shortfalls.

DOE has selected a particular waste package for DWPF and WVDP, namely, borosilicate glass in relatively thin-walled (3/8-inch-thick) stainless steel canisters. If vitrification proceeds according to schedule, some waste canisters will be produced and stored long before a repository exists to house them. Providing such storage at vitrification sites should not be a major technical problem. Storage for about 5 years operation of the DWPF has already been constructed at Savannah River. Either in on-site or monitored retrievable storage, the waste form should guarantee isolation from the environment for a thousand years or more if long-term institutional controls are in place and the waste form performs as designed.[50] The reported design lifetime of the DWPF canister is more than 8,000 years.[51]

According to present U.S. plans, no credit is allowed for the canister as a barrier to contact between the waste and the geologic repository in considering the acceptability of a waste package. The waste canister's role is to "encapsulate the waste glass during on-site storage, shipment, and temporary storage at the repository prior to overpacking and final disposal."[52] The canister must be able to withstand a drop of 7 meters without failure and must fit in the repository overpack container, as specified by the NRC.

The U.S. approach of placing no reliance on engineered barriers is in marked contrast to the Swedish approach to waste disposal. An evaluation of the latter by the National Academy of Sciences states that utilizing thick-walled canisters should enable the life of the waste form package to be extended to more than one million years (28). Some thought is also being given in the United States to placing more reliance on the engineered waste form. One issue for future inquiry identified in the first annual report of the Nuclear Waste Technical Review Board (NWTRB) to Congress concerns the relative importance of natural and engineered barriers.[53] Using longer-lived engineered barriers means that less reliance would have to be placed on geologic barriers or mathematical models of geologic performance when making licensing decisions (34).

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[47] S.P. Cowan, op. cit., footnote 11.

[48] Ibid.

[49] At an October 1990 visit to the DWPF, OTA personnel were told that operations with radioactive waste might not begin until FY 1993 or 1994 due to budget uncertainties.

[50] Should the repository be delayed, however, DOE would need to consider the issues of longer-term institutional controls and local public acceptance of on-site storage.

[51] S.P. Cowan, op. cit., footnote 11.

[52] Ibid.

If this were to occur, modification of existing designs might be required. Because the primary focus of the repository is commercial spent fuel, the NRC overpack container might have to be redesigned. This might have no effect on defense HLW canister design or it could necessitate changes. Current DOE plans and NRC requirements do not involve changing the waste canister, overpack, or container. If changes were anticipated, however, they would need to be balanced against the increased risk of delays in proceeding with vitrification of HLW tank contents.

Releases to the Atmosphere

The facilities involved in generating HLW—namely, nuclear reactors and reprocessing plants—as well as the facilities used to treat them, such as evaporators and calciners—sometimes release materials to the atmosphere. Early in the weapons program at Hanford, large releases of volatile fission products occurred when fuel was dissolved. More than 500,000 curies of iodine-131 was reportedly released to the air between 1944 and 1957 (41). Through the introduction of air filters and other off-gas handling equipment, releases of radionuclides have been reduced but not totally eliminated. At Savannah River in 1984, 1.7 million curies of radioactivity was released routinely into the atmosphere, most of which was tritium (790,000 curies) and krypton-85 (840,000 curies) (13). Accidental releases have also occurred. Fortunately, none has been as large as the Kyshtym radioactive waste tank explosion in the Soviet Union, in which an estimated 20 million curies, roughly 40 percent of the radioactivity associated with the Chernobyl accident, was released (15).

Several panelists at an OTA Health Effects Panel Workshop in January 1990 stated that airborne release of both radioactive and hazardous materials could be a greater potential health threat than groundwater contamination. They also pointed out that the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA, "Superfund") regulations focused attention on groundwater contamination but ignored air releases and that promulgation of standards for the release of radionuclides to air has become an object of contention between NRC and EPA.[54]

TECHNOLOGIES FOR IMPROVED MANAGEMENT OF HIGH-LEVEL WASTE

Introduction

Efforts are underway to improve the management of HLW at the three major DOE sites and at West Valley. A principal objective is to convert the liquid and semisolid HLW now stored in aging tanks to solids that can be immobilized and dispersed throughout a rigid matrix material, encased in canisters, and placed in a deep geologic repository. This would eliminate the threat of groundwater contamination from tank leaks or radioactive releases from tank explosions. The matrix material selected by DOE is borosilicate glass and the process of choice is *vitrification*. At the Idaho National Engineering Laboratory (INEL), some liquid waste has already been solidified into a powdery form by a process known as *calcination*. INEL is considering a variety of solid waste forms besides borosilicate glass to immobilize the calcine for final disposal.

Three of the facilities that manage HLW pretreat[55] it to some extent to reduce the volume that must be stored as liquid and then vitrified, and hence to reduce waste management costs. A variety of technologies are used to treat and dispose of the "non-high-level" fractions of what started out as HLW. Prominent among these are grouting (immobilization in grout or concrete[56]), followed by near-surface or at-surface disposal.

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[53] The NWTRB was established by a 1987 amendment to the Nuclear Waste Policy Act of 1982, as an outside panel of experts appointed by the President to review decisions of DOE's Office of Civilian Radioactive Waste Management (12).

[54] DOE provided the following information on standards for air releases from reprocessing and other operations: DOE requirements for controlling and reporting air releases are set forth in various DOE orders; emissions of both radioactive and nonradioactive air pollutants must be maintained as low as reasonably achievable. DOE orders also specify the need for compliance with local, State, and Federal clean air laws or regulations where they apply. The National Emissions Standards for Hazardous Air Pollutants (NESHAPS) in 40 CFR 61 apply to radioactive emissions from all DOE sites, and the Prevention of Significant Deterioration (PSD) regulations in 40 CFR 52 cover nonradioactive pollutants. In general, NESHAPS requirements are enforced by EPA regional offices, whereas PSD regulations are enforced by State agencies. Source: S.P. Cowan, op. cit., footnote 11.

[55] The term pretreatment is used in this paper to mean those steps taken to reduce the volume of HLW to be vitrified; it does not include calcination.

Finally, some effort is underway at DOE to consider how *waste minimization* might be applied to all aspects of waste management operations. HLW minimization is discussed later in this section.

Vitrification

Vitrification or, alternatively, *glassification*, as it is to be carried out at the Defense Waste Processing Facility (DWPF) at Savannah River, is a process in which high-level radioactive waste, after removal of mercury, aluminum, and other selected nonradioactive components, is mixed with ground borosilicate glass and sent to a melter that operates at 2,100 degrees Fahrenheit (74). The glass-waste mixture is transformed into molten glassified waste by the melter, which operates at a rate of 228 pounds per hour. The molten glassified waste is poured into stainless steel canisters with 3/8-inch-thick walls, in which the mass cools and solidifies into a hard glasslike substance, trapping the radioactive materials inside.

Each of the large Savannah River canisters weighs 1,100 pounds, and is 2 feet in diameter and almost 10 feet high. Each canister holds about 3,700 pounds of glass, of which approximately 94 pounds will be HLW; the radioactivity of the waste in an individual canister will be as high as 234,000 curies, generating heat at a rate of 700 watts (74). The canisters will be sealed, welded tight, and stored in a building near the glassification plant pending shipment to a geologic repository. It is estimated that 6,000 to 8,000 such canisters will be required to hold existing and projected waste at Savannah River (74).

In 1983 the decision was made by DOE to adopt borosilicate glass as the waste form of choice for solidifying and immobilizing HLW at Savannah River (46). This decision, along with subsequent decisions to use the same vitrification process and waste form at West Valley and Hanford, has been the basis for major investments in the DOE Nuclear Weapons Complex. The Defense Waste Processing Facility has been constructed at Savannah River at a capital cost of about $930 million[57] and is scheduled to begin operation in FY 1992.

Vitrification with borosilicate glass will be used in the West Valley Demonstration Project to immobilize HLW from commercial fuel and some Hanford fuel reprocessed at that location 20 years ago; after a series of delays, this plant should begin operating in FY 1995 at a cost on the order of one billion dollars, including decontamination and other operations (45). In November 1989, a $550 million contract was awarded by DOE for a third borosilicate glass vitrification facility, the Hanford Waste Vitrification Plant (HWVP), which is estimated to cost $1.4 billion when completed and will begin vitrifying waste around the turn of the century (6).

These plants, if successful, could go a long way toward eliminating the threat presented by HLW tank storage. In addition to immobilizing the waste by locking or "fixing" the radionuclides in a glass matrix, they substantially reduce the volume of waste (although not the radioactivity) and, if the waste package performs as designed, could shift concern about contamination from the present to hundreds or thousands of years in the future. Thus, a great deal depends, both substantively and in terms of financial investment, on the success of the HLW vitrification efforts at the Savannah River, West Valley, and Hanford sites. Furthermore, although DOE and its critics may disagree about specific technical decisions or factors, a general consensus is emerging that the move from liquid to solidified HLW is a good one.

Concerns about borosilicate glass vitrification fall into two main categories: 1) those that question the original decision to use borosilicate glass as the waste form and 2) those that accept the waste form decision and focus on improving the process. The original waste form decision is not discussed here, but is treated later in considering the choice of waste form at INEL, the one site that stores HLW as both liquid and solid (calcine) and has not yet selected a final waste form for repository disposal.

A long-time observer of the vitrification process has provided some insight into what might make it work.[58] The French developed a vitrification process 20 years ago based on early work in the United States. Subsequently, the British bought and adapted the proven French process but the United States decided to go its own way. Two fundamental differences between the United States and the French approaches are: 1) the United States will use a ceramic melter, whereas the French use a metallic melter, and 2) the French employ three key steps one after the other—chemical adjustment to destroy free acid, calcining to drive off moisture, and incorporation with glass; the United States, however, incorporates all three steps in one operation within the melter itself. The ceramic melter would appear to have advantages over the metallic one in terms of operating temperature and useful lifetime. However, performing all three operations in the melter offers a difficult technical challenge; if something were to go wrong, difficult repair work could lead to considerable delay compared with the French approach. One specific problem that must be guarded against is plugging of the melter due to settling of heavy, noble metals (palladium, platinum, etc.) that can short out the electrodes.

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[56] Despite the different terms used at different DOE facilities, this immobilization generally involves mixing the waste with cement and letting the product solidify. Terms used for the product are "saltstone" at Savannah River, "grout" at Hanford, and "cement" at West Valley.

[57] Personal communication from DOE to R.P. Morgan during visit to DWPF, Savannah River Site, Oct. 26, 1990.

Concern has been expressed that the waste processing facility at Savannah River will be operated without sufficient pilot-plant experience, and arguments have been made for running the plant initially like a pilot plant, with sufficient instrumentation to fully understand and carefully evaluate the operation (1). DOE contends it has sufficient experience, particularly with a key piece of equipment—the melter—to achieve successful operation.[59] The only question still to be resolved, according to the 1989 DOE Research, Development, Demonstration, Testing, and Evaluation Plan (48), was how to dispose of the melter, a large piece of equipment that will operate for only 2 or 3 years and become highly radioactive. In October 1990 a storage vault was being constructed for the melter.[60]

DOE has provided some insight into developmental decisions and work on the DWPF as follows:[61] Savannah River built and operated a 1/10th-scale joule-heated radioactive melter in 1977 and a half-scale melter in 1979. In 1980, a slurry rather than calcine was chosen as feed material, based on savings achieved through elimination of the calcine and "significant canyon space reduction." A second 1/10th-scale DWPF melter began operating in 1988 to test the full system. A replica half-scale melter was built and operated at Savannah River between 1980 and 1983, and a second half-scale melter was tested with simulated waste from 1986 to 1988.

According to Savannah River Site personnel, the largest melter that had been demonstrated with radioactive materials was 1/100th scale. Overall system tests with radioactive materials had been demonstrated at 1/200th scale; these tests established the equivalence of radioactive and nonradioactive processing. Larger-scale radioactive tests were not pursued because of cost; the smaller-scale tests fit within existing high-level radioactivity cave cells. The 1/10th-scale Integrated DWPF Melter System (IDMS) (nonradioactive) was started up in December 1988. Tests involving mercury removal began in December 1989, and work on noble metals started in June 1990; deposition of noble metals has caused problems in German and Japanese tests but problems are not expected at DWPF. The IDMS will be operated during startup of the DWPF to test system elements and serve as an "early warning system" for possible problems. Some modifications of the DWPF design were made as a result of IDMS tests.[62]

West Valley has operated a full-scale melter at temperature (but without radioactivity) for 5 years, producing about 100 canisters of glass logs.[63] WVDP officials also state that in one way or another, they have tested the whole system, including a 1/6th-scale test of the tricky sludge mobilization step. The West Valley melter is about half the size of the Savannah River melter. In the last year or two, increasing exchange of information has occurred among DOE's HLW vitrification projects, facilitated by a technical review group and a "glass producers' club."

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[58] A. Schneider, Georgia Institute of Technology, personal communication to R.P. Morgan, March 1990.

[59] Personal communication during high-level waste briefing, U.S. Department of Energy, Germantown, MD, October 1989.

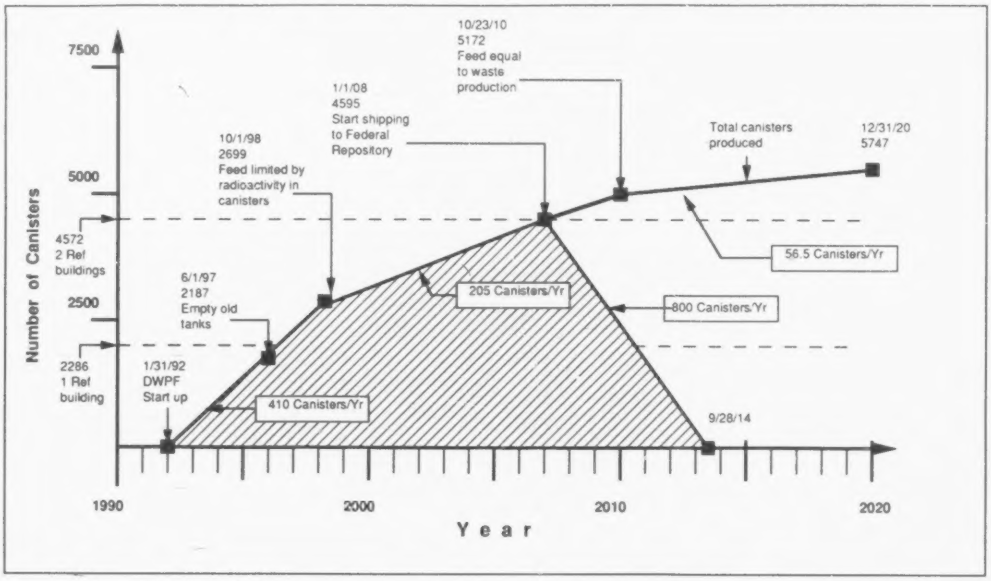
[60] Personal communication during visit of R.P. Morgan and P.A. Johnson to DWPF at Savannah River Site, October 26, 1990.

[61] S.P. Cowan, op. cit., footnotes 11 and 46.

[62] Based on conversations with DOE and Westinghouse Savannah River personnel during visit to DWPF, Savannah River Site, by R.P. Morgan and P.A. Johnson, Oct. 26, 1989.

[63] Personal communication during trip to West Valley Site, Feb. 21, 1990.

Figure 1-8—Storage Capacity for DWPF Glass Canisters



SOURCE: U.S. Department of Energy, April 11, 1990.

Vitrification plants are large facilities and will handle very large amounts of radioactivity. Some of the operations will involve transferring molten liquids, transporting slurries of radioactive waste, and mixing waste with glass. Some equipment will become highly contaminated with radioactivity. Equipment breakdown could occur. Given the nature of the facility, the health and safety of workers involved in plant operations—both routine operation or maintenance and unanticipated shutdowns or emergency procedures—must be protected. According to DOE, all major operations will be performed by remote control, and if equipment breaks down, it will be repaired in place with mechanical arms or removed and replaced with an overhead crane. Thorough equipment testing; reinforced concrete walls separating the process, maintenance, and control areas to provide radiation shielding; and personnel training during 2 years of simulated (nonradioactive) operation are some of the elements being employed to ensure worker safety and protection from radiation (74).

Requirements for interim storage of glass canisters at Savannah River have been based on certain assumptions about an opening date for a deep geologic repository (see figure 1-8). Figure 1-8 was prepared in April 1989; as of March 1990, some changes had been reported by DOE.[64] The start date had been delayed from January 31 to June 30, 1992; production rates had been reduced from 800 to 400 canisters per year from 2012 through 2020. Furthermore, shipments to a Federal repository are now not anticipated by DOE and NRC to begin before 2010. Therefore, HLW storage capacity may need to be expanded beyond that currently planned. The one existing Savannah River storage building cost $55 million in 1983 dollars.[65] [66]

If and when vitrified waste is placed in a deep geological repository, the waste form and canister offer lines of defense against radionuclides escaping into the environment. The resistance of the waste form to leaching and the ability of the canister to withstand infiltration or penetration over long periods of time (10,000 years or more) are important considerations. The Swedish approach to disposal gives more weight to the engineered barrier (i.e., the canister or overpack container) than the U.S. approach; the much thicker Swedish canister is designed to last 1 million years or longer, compared with several hundred to 1,000 years for the U.S. canister. The United States could also consider increasing the design lifetime required for the canisters or overpack containers. Currently, no standards are in place for long-term disposal of HLW since previous Environmental Protection Agency (EPA) standards were remanded by a court in part due to concern that disposal standards for HLW were not consistent with more restrictive drinking water standards. Further, a recent National Academy of Sciences report questions whether HLW disposal standards can be met with the current approach.[67]

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[64] S.P. Cowan, op. cit., footnote 11.

[65] Ibid.

[66] At West Valley, glass logs will be stored in a decontaminated cell area of the old plant. Source: Personal Communication during trip to West Valley site, Feb. 21, 1990.

If canisters or overpack containers with a longer design lifetime prove to be an attractive option, one question is when they should be redone. At this time, it is not clear whether canister designs for one or more of the three planned vitrification facilities can be changed, without considerable effort and cost.[68] Certain approaches could be studied, however, such as keeping the existing canisters but redesigning the overpack containers to provide greater assurance of long-term isolation of waste via engineered barriers.

Finally, the management structure for the vitrification activity could be questioned. One major corporation, Westinghouse, with its associated companies, is the contractor for work at all four HLW vitrification sites. This should facilitate communication and result in the experience gained at one facility being readily available to the others; in fact, cost projections for the Hanford Waste Vitrification Facility (HWVF) assume savings based on utilizing experience gained at Savannah River. However, this also means that one company has a monopoly on the technology and might be less willing to innovate and less receptive to learning about advances in vitrification technology outside the United States.

Calcination

Calcination of HLW has occurred at the Idaho National Engineering Laboratory periodically for over 25 years. This is a process in which liquid waste solutions are sprayed as a fine mist into a vessel containing heated granules about the size of coarse sand. The granules and waste solution are brought in contact with air that flows through and circulates the material in the vessel, an operation known as fluidization. In the hot fluidized bed, heat evaporates water and deposits dissolved aluminum and fission product nitrates as coatings on the granules. Small fragments chip off from the granules during agitation as particle size increases. Some fragments are carried aloft where they enter an off-gas cleanup system consisting of scrubbers, silica gel absorbers, and filters. Other fragments remain in the vessel to nucleate new granules. The solid, nonfragmented granules, or "calcine"—a dry, white, powdery substance that contains most of the radioactive material—is blown by air through a shielded underground tube to be stored in stainless steel bins inside reinforced concrete vaults (73).

Calcination began in the Waste Calcining Facility (WCF) in December 1963, following developmental work at two pilot plants in the 1950s; the WCF operated intermittently until March 1981, calcining approximately 3.9 million gallons of radioactive liquid waste. In October 1982 the New Waste Calcining Facility (NWCF) began operating; this facility, built at a cost of $92 million, can handle 3,000 gallons of waste per day. It has calcined at least 2 million gallons of HLW since it began operation (73). In December 1989 the NWCF, which had not operated since October 1988, was placed on a longer "temporary standby" condition, pending a review of ways to bring single-wall piping from some older storage tanks into compliance with Resource Conservation and Recovery Act (RCRA) standards (35). Calcination was not expected to resume at INEL until late 1990.

Calcination might be considered an intermediate step between liquid HLW and vitrified waste. The solid form of the calcine renders it less prone to tank leaks than liquid waste; furthermore, the volume of calcine, one-eighth that of the liquid, requires less storage space. The design lifetime of stainless steel storage bins for the calcine, 400 to 500 years, is perhaps an order of magnitude longer than that of the liquid HLW storage tanks, but perhaps two orders of magnitude shorter than required for a repository. All of the factors that caused INEL to pursue calcination, whereas Hanford, Savannah River, and West Valley chose vitrification, are not clear, but different organizations may simply have developed their own approaches.[69]

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[67] "Rethinking High-Level Radioactive Waste Disposal: A Position Statement by the Board on Radioactive Waste Management," National Research Council, 1990.

[68] Although an October 1989 predecisional draft of the DOE Research, Development, Demonstration, Testing, and Evaluation (RDDT&E) Plan included a discussion of the advantages of increased waste loading and canister redesign (50), the November 1989 DOE RDDT&E Plan (48) omitted these matters.

Given the seemingly modest cost and the proven nature of calcining compared with vitrification, what—if any—are its liabilities? First, gases from the calcining step must be cleaned up to meet EPA standards before release. Second, the powdery nature of the calcine could result in airborne dissemination if it is not handled properly or if storage bins are breached. In response to an inquiry about storage of calcine, DOE stated, "We know of no technical problems at this time to preclude long-term storage of calcine in the bins, based on their design and on measured corrosion coupon results. Observed corrosion rates support the design lifetime of 500 years. However, the calcine is a radioactive hazardous mixed waste whose long-term storage may not meet regulatory requirements such as the Land Disposal Restrictions (LDR)."[70] If DOE will be producing more HLW in the future, more attention should be given to the relative merits of the calcination process compared with tank storage followed by vitrification.

Alternative Waste Forms for the Idaho National Engineering Laboratory

Final choice of the longer-term solid form for HLW at INEL has not yet been made (49). Figure 1-9 shows some of the alternatives being considered in October 1989. Among these are the use of a glass-ceramic material for the matrix of the waste form in which the radioactive calcine would be embedded; that should permit higher radioactive waste loading (i.e., immobilization of a larger amount of radioactive material per canister) than borosilicate glass. The cost for disposal of one canister in a repository is cited by DOE as $350,000 (49). During a visit to INEL in July 1989, the following information was obtained: INEL anticipates a large increase in the fuel processing rate, resulting in a large HLW volume. If borosilicate glass vitrification is used to immobilize the calcine, production of 38,800 canisters is projected by the year 2020, corresponding to a disposal cost of $14 billion. However, if a glass-ceramic matrix being developed is used, an increase in the radioactive material loading will reduce the number of canisters by 2020 to 16,300, at a disposal cost of $6 billion. That cost might be lowered to $4 billion by changing the geometry of the canisters. INEL anticipates that the durability of the glass-ceramic will be similar to that of glass.[71] [72]

At present, given the economic incentive, most research and development on the long-term form for INEL HLW seems to be devoted to glass-ceramic. However, one alternative is not immobilizing the calcine in a glass-ceramic matrix but hardening it in storage bins, that is, using the hardened calcine itself within an engineered barrier as the final waste form. Such an alternative might not prove attractive for repository disposal, given the large volume of calcine, but if delays in opening the repository become lengthy, necessitating a de facto shift to on-site, monitored retrievable storage, or if problems arise in vitrification efforts, bin hardening of the calcine might well be worth a harder look. A March 1990 DOE communication considers bin hardening a "subordinate alternative for long-term storage of calcine. . . . Based on current calcine leach data and the fact that the Snake River aquifer is located below the INEL, the bin hardening option is not feasible. Bin hardening will be addressed as the No Disposal Action option in an EIS (Environmental Impact Statement) for the immobilization project."[73] A decision on a reference strategy and form for Idaho Chemical Processing Plant HLW is currently planned for FY 1993-94.[74]

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[69] Evidently, INEL fuels require large amounts of chemicals, including hydrofluoric acid (HF) to get them to dissolve. A substantial amount of aluminum is required to protect the tanks from HF. Thus, in hindsight, it could be argued that calcination might best have been employed at Hanford or Savannah River on acid liquid waste stored in stainless steel tanks, thus eliminating the difficulties in dealing with neutralized waste sludge and slurry; instead it was used on the more dilute waste at INEL (Source: A.G. Croff, Oak Ridge National Laboratory, personal communication to R.P. Morgan, June 28, 1990.). Such an approach was seriously considered in the late 1950s at Hanford. Idaho (and also the French and British) had the proper foresight not to neutralize the HLW and store it in acidic form in stainless steel tanks, thus greatly simplifying the subsequent selection of a solidification process. By contrast, the neutralized HLW at the three other U.S. sites cannot be calcined without complicated pretreatment processes.

[70] S.P. Cowan, op. cit., footnote 11.

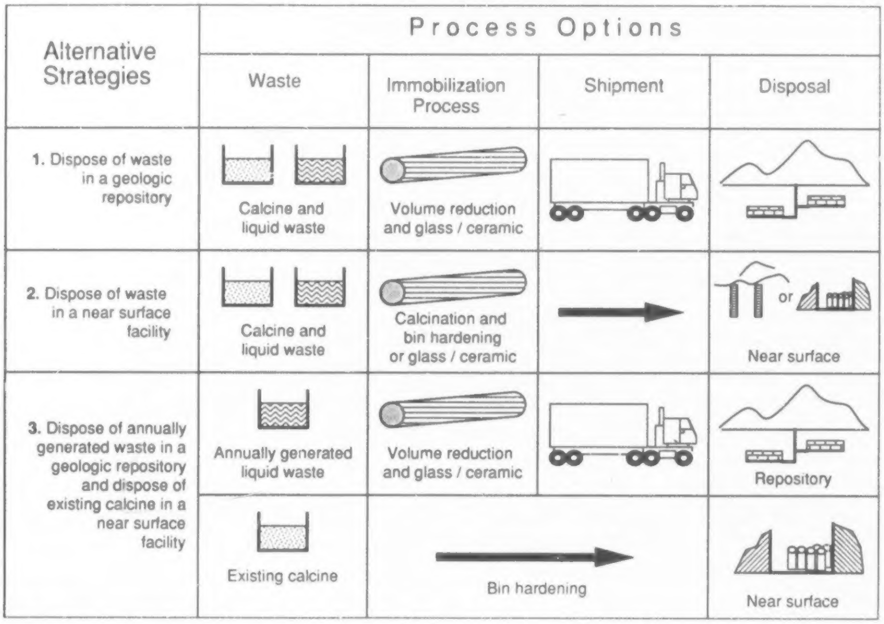
[71] This statement, of course, will need to be verified, probably by means of an extensive test program similar to that done with borosilicate glass over the past decade. Glass-ceramic and other ceramic materials had their supporters at the time the decision was made to use borosilicate glass for vitrification at Savannah River. A synthetic rocklike material called Synroc, also received attention about a decade ago.

[72] J. Solecki, op. cit., footnote 12.

[73] S.P. Cowan, op. cit.,footnote 11.

[74] J. Solecki, op. cit., footnote 12.

Figure 1-9—Alternative Long-Term High-Level Waste Management Strategies for the ICPP



Alternative Strategies	Process Options			
	Waste	Immobilization Process	Shipment	Disposal
1. Dispose of waste in a geologic repository	Calcine and liquid waste	Volume reduction and glass / ceramic		
2. Dispose of waste in a near surface facility	Calcine and liquid waste	Calcination and bin hardening or glass / ceramic	→	or Near surface
3. Dispose of annually generated waste in a geologic repository and dispose of existing calcine in a near surface facility	Annually generated liquid waste	Volume reduction and glass / ceramic		Repository
	Existing calcine	→ Bin hardening		Near surface

SOURCE: U.S. Department of Energy briefing, October 1989.

Technologies for Pretreatment of High-Level Waste

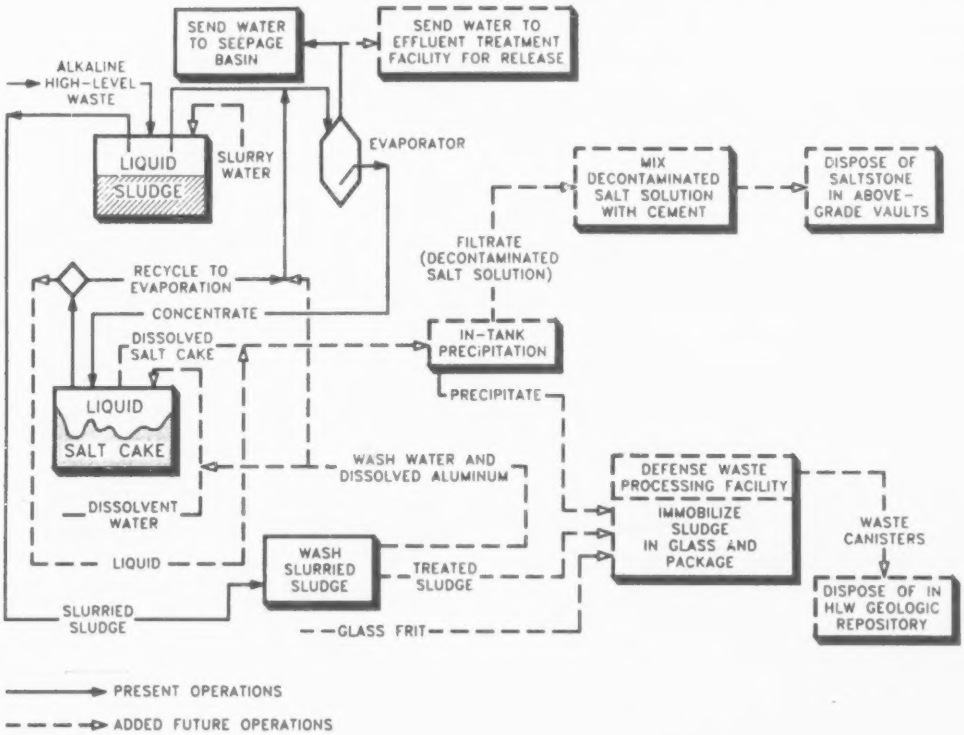
At the three sites gearing up to vitrify HLW, Savannah River, Hanford, and West Valley, the HLW streams coming from the reprocessing plants are subjected to one or more steps before vitrification, which OTA has referred to as *pretreatment*. Two objectives of pretreatment are to reduce the volume of liquid that must be stored in tanks and to remove that portion of the streams that can be disposed of as other than vitrified HLW. Both these actions are driven in part by economic incentives; in their absence, the cost of waste management would increase because of the need for additional storage tanks and because of the high cost of vitrification relative to cemented waste forms disposed of near the surface.

Figure 1-10 illustrates treatment methods for HLW in tanks and canisters at Savannah River. Note that evaporation is an important element in the system, reducing the volume of liquid in the tanks. According to a 1988 document, without evaporation, 69 additional waste tanks valued at more than $33 million each would have been required (65). Prior to 1989, some water from the evaporator, not totally free of radioactivity, was discharged to seepage basins; in 1989, OTA staff observed operation of the new effluent treatment facility, which uses filtration, reverse osmosis, and ion exchange to clean up evaporator discharge (66).

Two main operations emerge after a series of pretreatment steps, as illustrated on the right-hand side of figure 1-10. One is the vitrification operation itself. The other involves mixing a decontaminated salt solution from the waste streams with cement to form a substance called "saltstone," which will be disposed of in above-grade vaults. Making the saltstone is essentially a grouting or cementing operation of the kind used or planned for the disposal of some low-level waste (LLW). An approach that is similar overall but has some different steps to separate low-level streams is planned for Hanford HLW.

Various chemical operations plus radioactive decay with the passage of time are utilized to achieve low levels of radioactivity in the solution to be mixed with cement; some 99.9 percent of the aged waste supernatant will reportedly be removed (67). Among factors of interest to appropriate regulatory agencies are the amount and nature of the remaining

Figure 1-10—Treatment Methods for High-Level Waste in Tanks and Canisters at Savannah River


SEND WATER TO SEEPAGE BASIN
SEND WATER TO EFFLUENT TREATMENT FACILITY FOR RELEASE
ALKALINE HIGH-LEVEL WASTE
LIQUID
SLUDGE
SLURRY WATER
EVAPORATOR
MIX DECONTAMINATED SALT SOLUTION WITH CEMENT
DISPOSE OF SALTSTONE IN ABOVE-GRADE VAULTS
FILTRATE (DECONTAMINATED SALT SOLUTION)
RECYCLE TO EVAPORATION
CONCENTRATE
DISSOLVED SALT CAKE
IN-TANK PRECIPITATION
PRECIPITATE
LIQUID
SALT CAKE
WASH WATER AND DISSOLVED ALUMINUM
DEFENSE WASTE PROCESSING FACILITY
IMMOBILIZE SLUDGE IN GLASS AND PACKAGE
DISSOLVENT WATER
WASTE CANISTERS
LIQUID
WASH SLURRIED SLUDGE
TREATED SLUDGE
DISPOSE OF IN HLW GEOLOGIC REPOSITORY
SLURRIED SLUDGE
GLASS FRIT
PRESENT OPERATIONS
ADDED FUTURE OPERATIONS

SOURCE: U.S. Department of Energy, "Integrated Data Base for 1989," DOE-EW-0006, November 1989.

radioactivity, and the mixed (i.e., hazardous plus radioactive) nature of the saltstone. The amount of saltstone to be produced at Savannah River is very large, about 3 million tons over 28 years; long-lived isotopes include 60,000 curies of technetium-99 (14). DOE reports that the saltstone facility started operating in the summer of 1990, all necessary permits having been granted by EPA and the State of South Carolina.[75] [76] Furthermore, saltstone has evidently been ruled a nonhazardous waste form;[77] that is, in contrast to Hanford grout (see below), it is not considered a mixed waste. According to Savannah River officials, the saltstone contains much lower concentrations of organic material compared with the Hanford grout. This may account for the markedly different regulatory treatment.

The saltstone developmental process has not been without problems. In late 1987 it became evident that the organic chemicals used to decontaminate the salt solution created a flammability hazard; furthermore, the amount of benzene in the decontaminated filtrate sent to the saltstone facility did not meet new environmental standards. Modifications were made that should be in place (68). Further insight into the complex number of steps required prior to and in parallel with vitrification is given in the Savannah River Waste Management Operations Program Plan of 1988 (69).

The saltstone facility at Savannah River began operation in June 1990. As of that date, the only radioactive materials that had been immobilized and placed in the saltstone facility were streams from the

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[75] P. Washer, U.S. Department of Energy, personal communication to R.P. Morgan, July 18, 1990.

[76] S.P. Cowan, op. cit., footnote 11.

[77] Ibid.

Effluent Treatment Facility and some wastes from tests of the in-tank precipitation (ITP) process that were carried out in 1983 and 1984. It will take about one year to fill one vault of the saltstone facility once operation of the pretreatment operations begins on the HLW tank wastes.

One key technical step that is new and has been the cause of some problems is precipitate hydrolysis, to be carried out within specially designated waste tanks, and referred to as ITP. The purpose of this process is primarily to remove radioactive cesium from the waste stream that will be sent to the saltstone facility. As of October 1990, Savannah River personnel were hopeful that radioactive operations of ITP would begin in April 1991; this would signal the start of pretreatment of HLW tank waste and immobilization of a non-high-level component in the saltstone facility.

The precipitate hydrolysis process at Savannah River involves the use of benzene, which emerges as a radioactive mixed waste. Plans call for building an incinerator to burn the benzene; until this occurs, it will be necessary to store the benzene in tanks.[78]

At other DOE HLW sites, there are some parallels to, and differences from, what is planned for Savannah River. At Hanford, the double-shell tank wastes are complex mixtures from a variety of operations, including a plutonium finishing plant (62). In 1990, Hanford began producing grout in the facility to be used in connection with the vitrification plant. The grout for the first run was "low-level" waste that was not "mixed" in nature. The grout facility is designed for mixing 1 million gallons of liquid with cement and producing 1.4 million gallons of grout;[79] the conversion actually increases waste volume. Like Savannah River, Hanford has been concerned about obtaining the necessary permits for grouting a portion of what started out as HLW. It has also shut down a key evaporator because of the presence of hazardous wastes in process condensates and the disposal of hazardous wastes directly in cribs, which violated either EPA or Washington State Department of Ecology regulations.[80] Mixed-waste regulatory issues are being addressed through the process of obtaining a RCRA Part B permit from the State of Washington Department of Ecology.[81]

At West Valley, processing of high-level alkaline liquid waste began in May 1988 to remove cesium-137 from the supernatant by ion exchange so that some of the waste can be treated as low-level waste (62). As of February 1990, more than 99.9 percent of the cesium-137 had been removed from more than half of the liquid in the larger of the two West Valley waste tanks; the liquid with the cesium removed had then been mixed with portland cement and stored on site in specially designed, easily stackable 71-gallon square drums in a storage building about 200 yards from a public road.[82] The cesium is captured by inorganic ion exchange on zeolite, which is stored for subsequent vitrification. Thus, West Valley leads other sites in the pretreatment of waste destined for vitrification by grouting a low-level fraction. The regulatory basis cited by DOE for this pretreatment is the West Valley Demonstration Act of 1980; the NRC is accorded special status in this act because of the commercial origin of the fuel that was processed into HLW. NRC does not have such a role in weapons sites such as Hanford and Savannah River. At West Valley, DOE sought and obtained NRC approval for the immobilized waste form from the pretreatment process.

The West Valley Demonstration Project was sued by citizens groups when it attempted to convert the building containing the drums with grouted waste into a permanent disposal facility. According to DOE, that building is the only "certified Class-C (low-level waste) cement farm in the country."[83] From the DOE-WVDP point of view, radiation at drum surfaces was lower than anticipated because of better than anticipated cesium removal. Nevertheless, in an out-of-court settlement, DOE and WVDP agreed to study the matter and use the National Environmental Policy Act[84] (NEPA) process to decide upon disposal by preparing an Environmental Impact Statement (EIS) not only for the drum building but also for the entire West Valley site. In the meantime, on-site disposal is precluded; presumably, temporary storage is not. The EIS process should provide a forum for those concerned about above-ground storage of Class C low-level waste (38). Issues that might be scrutinized include the presence of technetium-99, a very long-lived, somewhat mobile, radionuclide in the grout at levels of 30 nanocuries per gram[85]; the integrity of the grout; and its ability to contain radionuclides over time.

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[78] Personal communication during trip to Savannah River Site, Oct. 26, 1990.

[79] Personal communication during visit to Hanford, November 1990.

[80] Viewgraph obtained during visit to Hanford, November 1989.

[81] S.P. Cowan, op. cit., footnote 11.

[82] Personal communication during trip to West Valley site, Feb. 21, 1990.

[83] Ibid.

[84] Pub. L. No. 91-190, 83 Stat. 852 (1970) (codified as amended at 42 U.S.C.A. §§4321-47) (West 1983 and Supp. 1990).

At INEL, examination of a simplified flow sheet depicting HLW treatment indicates that to date, acid HLW flows directly to the calciner without pretreatment (60). An elaborate off-gas treatment system operates to control the radioactivity of effluent from the calciner. In planning further treatment of the calcine, consideration is being given to removing ''inerts'' (nonradioactive materials) from the calcine prior to immobilization (48). The efficiency, environmental impact, and regulatory requirements of this separation must all be considered; such a separation would appear to be somewhat analogous to HLW-LLW pretreatment separations being implemented at other sites.

Waste Minimization

Waste minimization is receiving increased attention at DOE. The charter of DOE's Waste Reduction Steering Committee defines waste minimization as ''any action that minimizes the volume or toxicity of waste by: 1) avoiding its generation, or 2) recycling'' (60). Given this definition, if defense HLW alone is considered, minimization is intimately involved with production levels and methods for producing plutonium and tritium.

Several scenarios might be considered. If no more plutonium or tritium is produced, no more HLW will be generated.[86] If one or more of the Savannah River reactors is restarted to produce plutonium or tritium, the radioactivity generated should probably be compared with the radioactivity that would be created if the same amount of material were produced in a new reactor designed to maximize the ratio of plutonium or tritium production to that of fission. If only tritium is produced in a reactor, DOE might consider whether a higher ratio can be achieved by producing only tritium.

Although an examination of reactor technologies could indicate possible HLW minimization, the savings are unlikely to be significant. Major reductions in HLW generation for this case appear to be possible only through reduction in plutonium and tritium production in nuclear reactors, production of tritium by a radically different method such as a linear accelerator, or substitution of uranium-235 for plutonium.[87] This conclusion arises because HLW is an inevitable outcome of producing weapons fuel in a nuclear fission reactor.

However, for the second case in which spent fuel is not included within the definition of HLW, then one way of minimizing HLW generation is to reprocess only the lithium targets used to produce tritium and not to reprocess either the driver fuel elements or the depleted uranium targets used for plutonium production. According to this definition, processing to recover plutonium produces HLW whereas processing to recover tritium does not. An argument for proceeding in this manner is that the material more likely to be in short supply, namely tritium, could be produced in this manner without creating additional liquid HLW tank waste that must be dealt with. Furthermore, it might be argued that although both HLW and spent fuel will eventually be disposed of in deep geologic repositories, spent fuel is more cheaply, easily and safely treated and/or stored than HLW on an interim basis. On the other hand, the cost of running reactors fueled with enriched uranium for tritium production might increase if the fuel elements were not reprocessed. Furthermore, whether or not the spent fuel is reprocessed, the radioactivity to be dealt with will be the same.

At the next step in production—reprocessing—certain advantages may be derived from the use, reuse, and handling of hazardous materials because it could possibly make the waste management system simpler. Despite modernization of certain components and subsystems, most reprocessing plants and technology in the United States are 30 to 40 years old. New approaches that build on experience in other fields and possibly outside the United States, where commercial reprocessing activity has been pursued that utilizes smaller and more modern equipment, might well be possible.

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[85] Personal communication during trip to West Valley site, Feb. 21, 1990.

[86] This ignores the fact that HLW could still be produced from spent fuel that has not been reprocessed at certain DOE sites.

[87] This assumes that uranium-235 is obtained by a process such as gaseous diffusion or centrifugation that does not involve its recovery from spent fuel in a nuclear reactor.

Any efforts that minimize the generation of HLW have intrinsic merit because of the threat posed by the intense radioactivity associated with it. Moreover, because HLW and spent fuel are at the top of a pyramid that broadens to include other waste types (i.e., low-level, mixed, and transuranic), decreasing HLW generation will also reduce the problems created by waste in these other categories.[88]

REGULATORY FRAMEWORK

Introduction

Historically, the regulatory framework and standards for high-level waste (HLW) at Department of Energy (DOE) weapons sites have long been the province of DOE and its predecessor agencies under the Atomic Energy Act.[89] The primary vehicle for specifying the definition, handling, and treatment of defense HLW has been by DOE order, in which the Secretary of Energy has the final authority. However, the Nuclear Regulatory Commission (NRC) becomes a factor in establishing licensing criteria for disposal of defense HLW. According to current plans, vitrified HLW is to be placed in the same deep repository as spent fuel from commercial reactors; criteria for the repository and for the waste forms to be placed therein are governed by the NRC.[90] Environmental standards for repository disposal of HLW are the responsibility of the Environmental Protection Agency (EPA). Furthermore, EPA's role in radiation protection standard setting has been growing and affects DOE's HLW management activities. EPA is the lead agency in a Federal interagency committee to prepare Federal guidance on radiation protection of the public. EPA is also primarily responsible for setting environmental radiation standards for specific practices or sources, although criteria developed by NRC for the commercial sector or DOE for the defense sector can apply if they are more stringent than EPA standards (23).

EPA regulates waste management practices at DOE weapons sites through its jurisdiction over hazardous wastes and the application of the Resource Conservation and Recovery Act (RCRA) and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). Its role in regulating hazardous waste and the hazardous components of mixed waste is broadly based. It is mainly with regard to hazardous materials that regulatory pressure and actions are being brought to bear on DOE. Two examples at Hanford are: 1) shutdown of the 242-A evaporator in April 1989 because process condensates contained hazardous "listed wastes"[91] (e.g., acetone) and 2) prolongation of the shutdown of the Plutonium Production and Extraction (PUREX) reprocessing plant, beginning in December 1988, in part because acetone and other listed wastes were being used and discarded. The latter two actions are in response to RCRA, which governs ongoing waste management operations.

Strictly speaking, all HLW is mixed waste; that is, it has both hazardous and radioactive components. It might be argued that because the health threat represented by the radioactivity of HLW far outweighs the health threat associated with the hazardous component of that waste, any actions that DOE takes to provide adequate protection against radioactivity would provide more than adequate protection against the hazardous component. However, this argument does not appear to be accepted in the regulatory sense, nor need it prove correct in all situations having to do with storage, treatment, transport, and disposal of HLW.

State agencies have also become factors in regulation through interagency agreements. For example, at Hanford, the Federal Facility Agreement and Consent Order, the so-called tri-party agreement, entered into in May 1989 by the Washington State Department of Ecology, EPA, and DOE, governs the Hanford cleanup (71). In the Hanford tri-party agreement, milestones are set forth for vitrification of HLW from double-shell tanks, and a more expanded schedule involves further study before any action is taken for single-shell tanks. A 1989 report sets forth the very complex set of regulations that might govern the treatment of single-shell tanks and tank wastes (22).

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[88] This discussion of HLW minimization focuses on radioactivity, the overwhelming contributor to its toxicity. Often, analyses of waste minimization concentrate on reducing the volume of the waste; accordingly, the volume reductions achieved by vitrifying or calcining a given amount of HLW might have been compared. However, reducing the volume after the waste has been generated does not fit the concept of waste minimization as defined by the DOE Waste Minimization Steering Committee; nor, in the case of HLW, does it really get to the heart of the problem. Volume reduction considerations are relevant to pollution prevention and cost savings, and appear throughout DOE planning and this report.

[89] In 1970, the first regulatory definition of high-level waste was developed by the U.S. Atomic Energy Commission in 10 CFR Part 50, app. F.

[90] This authority is vested in the NRC by the Nuclear Waste Policy Act (NWPA) [Pub. L. 91-190, 96 Stat. 2201 (1983) (codified) at 42 U.S.C. §§10101-10226] and also applies to the case where defense HLW is not comingled with spent fuel but placed in a separate repository.

[91] "Listed wastes" are substances that have been placed on the RCRA-based list of hazardous materials and are thus subject to EPA regulation. In this report, the term "hazardous" is used in this sense; in other words, radioactivity, although a hazard, is not "hazardous."

Definition of High-Level Waste

The definition of *high-level waste* contained in both the DOE 1989 Five-Year Plan (55) and the draft DOE Order No. 5820.2A (63) is as follows:

> . . . the highly radioactive waste material that results from the reprocessing of spent nuclear fuel, including liquid waste produced directly in reprocessing and any solid waste derived from the liquid, that contains a combination of transuranic waste and fission products in concentrations requiring permanent isolation.

The last five words of this definition introduce the idea of a definition based on the *concentration* of radionuclides in the waste and not solely on the *source* of the waste, namely, liquid waste produced directly in reprocessing. In recent years, the issue of a source-based v. a concentration-based definition has arisen because strict application of the former would require the treatment and disposal of much larger amounts of liquid HLW currently stored in tanks, thus greatly increasing overall costs. If some waste of lower radioactivity could be separated and treated as low-level waste, costs would decrease not only because of reduced disposal costs but also because of more effective use of existing HLW tank storage space. On the other hand, if such a redefinition is not allowed and a strict interpretation of the existing source-based definition promulgated by the NRC and listed in the *Code of Federal Regulations* is adhered to,[92] DOE's cleanup plans could be affected very substantially. Presumably, the definition is based not only upon cost considerations but also upon consideration of health effects and potential health risks.

The issue is particularly relevant to the waste at Hanford and Savannah River. Both of these facilities expect to reduce the amount of HLW by separating a large "low-level" waste component from the reprocessing streams prior to vitrification. At Savannah River, this involves separation of a salt solution that has been decontaminated of at least 99.9 percent of its radioactivity; the salt solution will then be mixed with cement to form saltstone and disposed of on-site in above-grade vaults (see figure 1-10). At Hanford, HLW is to be pretreated by a series of steps that will separate "low-level" liquid streams to be grouted and then disposed of on-site in near-surface vaults. The specific technical steps differ, but the net result is the same. Figure 1-11 illustrates the reason for interest in this approach: the cost of HLW treatment and disposal by vitrification is about two orders of magnitude greater than the cost of LLW treatment and disposal.

In November 1989, the NRC gave tentative approval to a DOE plan to grout and then pump into concrete vaults some of the high-level tank waste at Hanford. According to a State of Washington estimate, "As much as 10 percent of Hanford's HLW could be put in low-level vaults because technical difficulties prevent the separation of all the high-level material from less radioactive components . . ." (3). Officials of the State of Washington called for an independent assessment of that decision. However, a DOE spokesman said that DOE has a reasonable, cost-effective plan for dealing with the waste (3).

These conflicting views can be interpreted in the context of how HLW is defined and who has regulatory authority over it. NRC is involved because of its responsibility for the HLW repository. Evidently DOE argued, and NRC concurred, that the material to be grouted, regardless of its source, had concentrations that resemble low-level waste and should be governed as "incidental waste" under a rule from the 1970s.[93]

The HLW definitional issue, as perceived by environmental groups, arose in what they viewed as a DOE effort to redefine Hanford single-shell tank waste so that it could be left in the tanks as a cost-saving but potentially dangerous means of disposal.[94]

The source-based definition of HLW still appears to be the official one, and the NRC interpretation does not appear to permit redefinition of the Hanford single-shell tank waste. However, it does appear to

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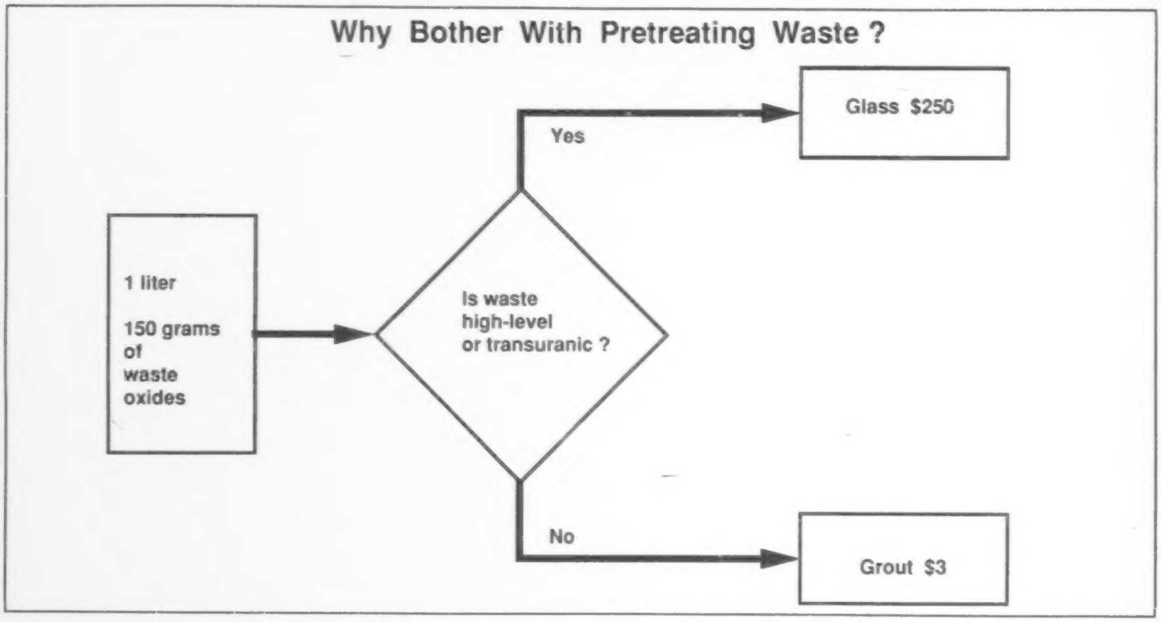
[92] Code of Federal Regulations. 10 CFR 0.735-1, Title 10, Energy, Chapter I, Nuclear Regulatory Commission, Part 60, Subpart A, p. 542.

[93] Personal communication during visit to Hanford, November 1989.

[94] What DOE may have had in mind is treating single-shell tank waste in situ, that is, at the site by vitrification or some other means. In situ treatment is believed by some to have two major advantages over removal and treatment: namely, it should be considerably less costly and should pose less of a health risk to workers. Whereas this may be an appealing alternative technically, the political difficulties associated with it are significant.

Figure 1-11—Economics of Pretreating Hanford Waste


Why Bother With Pretreating Waste ?
1 liter
150 grams of waste oxides
Is waste high-level or transuranic ?
Yes
Glass $250
No
Grout $3

SOURCE: U.S. Department of Energy, Hanford Plant, November 1989.

allow redefinition of a portion of Hanford HLW for disposal as low-level waste by grouting.[95]

The grouting of a "low-level" fraction of high-level tank waste is currently underway. As of mid-1990, more than half of the low-level fraction at West Valley had been grouted. The Savannah River saltstone operation has begun operating with waste from the effluent treatment facility. The low-level fraction of Savannah River tank waste is expected to be treated at the saltstone facility starting in mid-1991. Hanford is also proceeding to get necessary approval, in accordance with the tri-party agreement, to grout portions of tank waste. Thus the definitional issue may be of only academic interest. It could resurface, however, if questions arise about disposal of the grouted "Class C low-level waste" resulting from the current approach, which appears to be happening at West Valley.

At West Valley DOE moved vigorously forward with a program of pretreating the HLW to reduce the HLW disposal burden. There was at least one attempt in the mid-1980s to redefine the various waste categories (2). That effort did not succeed however and pretreatment is now being carried out as planned.

In December 1990, the States of Washington and Oregon petitioned the NRC to initiate rulemaking to redefine HLW as follows:[96]

> HLW means: (1) Irradiated reactor fuel, (2) Liquid wastes resulting from the operation of the first cycle solvent extraction system, or equivalent, and the concentrated wastes from subsequent extraction cycles, or equivalent, in a facility for reprocessing irradiated reactor fuel, and (3) Solids into which such liquid wastes have been converted; provided that if, prior to disposal, defense reprocessing tank wastes are treated to remove the largest technically achievable amount of radioactivity on a tank-by-tank basis . . ., the treated residual fraction shall be considered an incidental waste and therefore not HLW.

The States apparently took this action because they feared that wastes in the Hanford tanks could be designated as low-level waste and disposed of in a facility conforming to EPA requirements but unlicensed by the NRC.[97]

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[95] The question might be raised as to what authority NRC has over this matter. There appears to be no explicit authority as in the case of West Valley.

[96] Federal Register, vol. 55, No. 242, Dec. 17, 1990.

[97] *Weapons Complex Monitor*, Dec. 31, 1990, p. 3.

Regulations Affecting Single-Shell Tanks

Regulatory requirements important to waste management decisions for the Hanford single-shell tanks are summarized in a Pacific Northwest Laboratory report (22). The number of regulations and regulatory bodies that will govern tank cleanup is large, and the process is complex (see figure 1-12 and table 1-2). Uncertainties and conflicts could very well arise, some of which may be resolved as tank contents are better characterized. Many issues have not yet been resolved, involving waste definitions, mixed-waste disposal, and groundwater protection requirements.[98] RCRA may not provide sufficient quantitative criteria to assess the performance of proposed disposal systems, and variances from some applicable RCRA regulations for tank storage systems may be needed to remain in compliance. Some emphasis is needed to determine quantitative criteria, other than those in RCRA, that can be used for guidance in areas such as groundwater protection (22). Attention should be paid to regulatory requirements as the waste characterization process continues.

Taking core samples from tanks to characterize the waste and analyzing these samples can expose workers to radiation that exceeds ALARA (as low as reasonably achievable) limits. Modifications have been proposed to the EPA guidelines for testing methods to be used in the evaluation of solid hazardous waste (21). These modifications specifically focused on sampling and analysis procedures for the highly radioactive single-shell tank waste. In early 1990, EPA did propose to amend testing and monitoring regulations for hazardous wastes under Subtitle C of RCRA.[99]

Regulations Affecting Restart of PUREX

The regulations external to DOE that affect restart of the PUREX plant are concerned mainly with hazardous wastes. First, a major waste management evaporator at Hanford, the A-242 evaporator, was placed on temporary standby because hazardous waste was being disposed of in cribs and because process condensates contained hazardous waste, as defined by the State of Washington Department of Ecology regulations. DOE and Westinghouse-Hanford believe that restart of the evaporator is essential in reducing the volume of liquid waste to be accommodated in double-shell tanks so that new waste from the PUREX restart can be pumped to those tanks.

The PUREX plant itself is shut down for a variety of reasons. The initiating event in December 1988 was a "limiting condition of operation" violation in which the steam pressure in a line fell below the 185 pounds per square inch required for operation.[100] In addition, the PUREX process uses a variety of organic materials and solvents that are hazardous wastes regulated under RCRA.

Concerns were expressed about how the plant and its aging components might behave during restart, after having been shut down for an extended period in mid-campaign. In December 1989, DOE undertook to operate the plant for several weeks to clean out materials that had lodged in the system during shutdown and to stabilize the plant for an extended shutdown of about a year, prior to restart for normal operations (75). In October 1990 DOE announced that it would not restart PUREX for at least 2 years but would prepare an Environmental Impact Statement to evaluate a variety of treatment and disposal methods for stored N reactor fuel.[101]

Finally, it should be noted that the regulation of hazardous wastes at DOE sites under RCRA gives EPA and authorized States a mechanism whereby they can exert some regulatory control over DOE's waste management activities. In certain instances, the conditions involving hazardous waste that need correction may not appear very threatening, compared with the dangers posed by the radioactive components of the system. Nevertheless, the regulatory agencies have used the only authority available to exercise control over these DOE activities.

Regulations Affecting Vitrification

It seems reasonable to assume that under the current framework, DOE will have major regulatory authority for the vitrification process itself. However, there is an important interface with the NRC which, in turn, interfaces with EPA. NRC is

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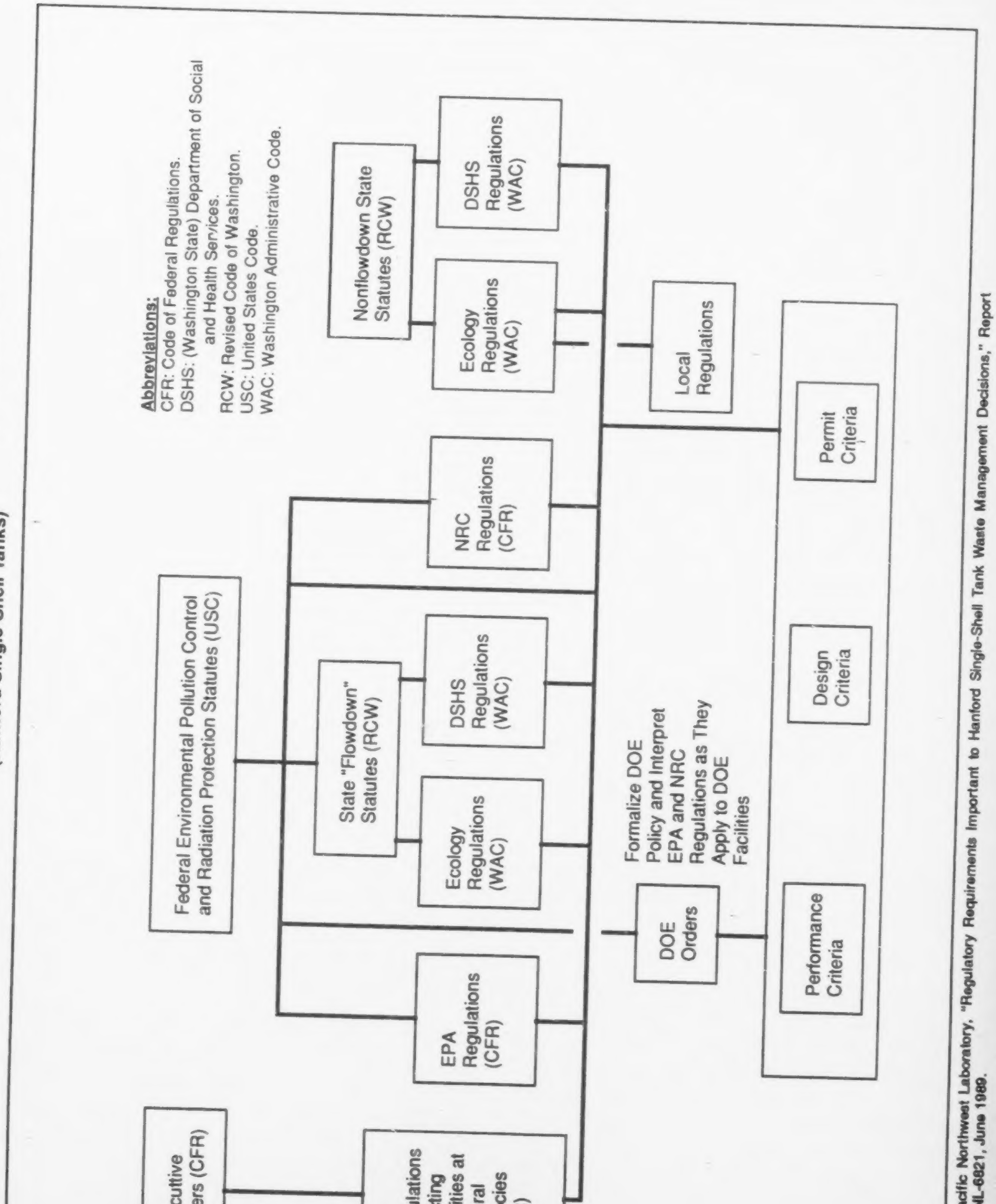
[98] As of March 1991, there are no groundwater protection standards for radionuclides. EPA has stated that they intend to propose such standards by June 1991 and would expect to promulgate them by mid-1993. (Personal communications with EPA, Mar. 21, 1991.)

[99] S.P. Cowan, op. cit., footnote 11.

[100] This event was of considerable concern because the plant was not shut down immediately when the limiting condition of operation was detected.

[101] N.K. Geranios, op. cit., footnote 6.

Figure 1-12—Regulations for Management and Disposal of Nuclear and Hazardous Waste (Hanford Single-Shell Tanks)


Executive Orders (CFR)
Regulations Affecting Activities at Federal Agencies (CFR)
EPA Regulations (CFR)
Federal Environmental Pollution Control and Radiation Protection Statutes (USC)
State "Flowdown" Statutes (RCW)
Ecology Regulations (WAC)
DSHS Regulations (WAC)
NRC Regulations (CFR)
Nonflowdown State Statutes (RCW)
Ecology Regulations (WAC)
DSHS Regulations (WAC)
DOE Orders
Formalize DOE Policy and Interpret EPA and NRC Regulations as They Apply to DOE Facilities
Local Regulations
Performance Criteria
Design Criteria
Permit Criteria
Abbreviations:
CFR: Code of Federal Regulations.
DSHS: (Washington State) Department of Social and Health Services.
RCW: Revised Code of Washington.
USC: United States Code.
WAC: Washington Administrative Code.

SOURCE: Pacific Northwest Laboratory, "Regulatory Requirements Important to Hanford Single-Shell Tank Waste Management Decisions," Report PNL-6821, June 1989.

responsible for overseeing performance testing of the HLW form in the repository. DOE is responsible for setting preliminary specifications for this waste form and for ensuring that it will comply with the repository requirements—the so-called "waste acceptance process."[102] Thus, coordination and cooperation between the two agencies are called for.

The performance of the waste form in the repository will be governed by standards promulgated by EPA for the management and disposal of spent fuel and of transuranic and HLW. Such standards were established in 1985 (40 CFR Part 191); however, they were vacated by the First Circuit Court in 1987 and remanded to EPA for further proceedings (16). At present, no new formal proposal has been published by EPA. Disposal standards for HLW were expected to have appeared for public comment late in 1990.

At a briefing at Savannah River in October 1990, the following information about oversight and monitoring of the vitrified waste form was obtained.[103] The DOE's Office of Civilian Radioactive Waste Management (OCRWM) has set up specifications for acceptance of the vitrified glass product. A Waste Form Compliance Plan has been submitted to the OCRWM and a Waste Form Qualification Report is being prepared; these reports are reviewed by an internal DOE Technical Review Group. Later, a Production Records report will be written to provide data as to whether the glass form complies with specifications. The OCRWM is the organization that interfaces with the NRC in connection with the repository; OCRWM will transmit these reports to the NRC.

The glass specifications are being based on the NRC technical criteria for the repository under 10 CFR 60 rather than the EPA disposal standards for the repository promulgated at 40 CFR 191. New methods are being developed to obtain and characterize product samples; these methods are being submitted for review by the American Society for Testing Materials, a national certification organization.[104]

Table 1-2—Legislation and Regulations Applicable to Hanford Single-Shell Tanks

Directly applicable legislation:
- The Resource, Conservation and Recovery Act (RCRA), the Washington Hazardous Waste Management Act, the Washington Solid Waste Management Act, and their implementing regulations.
- The Clean Air Act (CAA), the Washington Clean Air Act, the Washington Statute on Nuclear Energy and Radiation, and their implementing regulations.
- The Atomic Energy Act (AEA) and applicable implementing regulations.

Other legislation and implementing regulations:
- The Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), the Superfund Amendments and Reauthorization Act (SARA), the Emergency Planning and Community Right-to-Know Act (EPCRA).
- The Safe Drinking Water Act (SDWA).
- The Federal Water Pollution Control Act (FWPCA), as amended by the Clean Water Act (CWA); the Washington Water Pollution Control Act.
- The Nuclear Waste Policy Act (NWPA) and the Low-Level Radioactive Waste Policy Act (LLRWPA).
- The Washington Water Well Construction Act.
- The Washington Pollution Disclosure Act.
- The Washington Regulation of Public Groundwaters statute.

DOE orders relevant to waste management, environmental pollution control, and radiation protection:
- DOE Order 5400.1, General Environmental Protection Program (November 9, 1988).
- DOE Order 5820.2A, Radioactive Waste Management (September 26, 1988).
- DOE Order 5480.1A, Change 6, Environmental Protection, Safety, and Health Protection Program for DOE Operations (August 13, 1981).
- DOE Order 5480.1B, Environmental Protection, Safety, and Health Protection Program for DOE Operation (September 23, 1986).
- DOE Order 5481.1B, Change 1, Safety Analysis and Review System (May 19, 1987).
- DOE Order 5480.11, Radiation Protection for Occupational Workers (December 21, 1988).
- DOE Order 5480.11A, Requirements for Radiation Protection (September 17, 1986).
- DOE Order 5490.1A, Chapter XI, Requirements for Radiation Protection (August 13, 1981), updated by DOE Order 5480.1, Change 6 (August 13, 1981).
- DOE Order 5480.4, Environmental Protection, Safety and Health Protection Standards (May 15, 1984), updated by DOE Order 5480.4, Change 1 (May 16, 1988).

SOURCE: Pacific Northwest Laboratory, 1989.

EPA's role in regulating the waste form is, at the moment, unclear. The HLW to be vitrified has RCRA hazardous materials and is therefore a mixed waste. In mid-1990, EPA designated vitrification as Best Demonstrated Available Technology (BDAT) for mixed HLW.[105] Although DOE and Westinghouse-Savannah River officials have met with EPA officials to discuss the matter, it still appears to be an open question as to whether or not EPA will require proof of vitrification. DOE seems to be proceeding on the basis that EPA may be a factor in monitoring the waste form and is developing a test that might be substituted for the EPA Toxics Characterization and Testing Protocol (TCTP); the latter can not be performed in a hot cell.[106]

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[102] Personal communication at high-level waste briefing, U.S. Department of Energy, Germantown, MD, October 1989.

[103] Personal communication during visit to Savannah River Site, Oct. 26, 1990.

[104] Personal communication during visit to Savannah River Site, Oct. 26, 1990.

[105] Land Disposal Restrictions for Third Third Scheduled Wastes, 55 Fed. Reg. 22520, 22627 (1990).

Whether or not EPA monitors the vitrified waste form after production and during storage appears to be an open question. The answer may depend more upon the inclination and actions of the principal organizational players, namely DOE, EPA, and perhaps NRC, than on clear-cut existing regulatory requirements.

Associated with the vitrification process and usually one step ahead of it is the production of an immobilized grout or "saltstone." The saltstone facility at Savannah River has been granted a permit by the State of South Carolina as a nonhazardous waste facility. Thus, it is apparently not subject to EPA regulation. This is in contrast to the Hanford grout facility where continuing EPA presence seems assured by the larger component of hazardous materials in the waste. DOE monitors the saltstone product and produces monthly reports. Internal oversight is provided by DOE's Office of Environment, Safety and Health.[107]

DISCUSSION

Definition of High-Level Waste

In recent years, attempts to redefine high-level waste (HLW), moving from a source-based to a concentration-based definition, have occurred and have caused some controversy. The definition used can have a substantial impact on cleanup and waste management operations and costs. The Department of Energy (DOE) has proceeded to follow a concentration-based definition in pretreating HLW prior to vitrification so that a portion of tank waste can be disposed of as low-level waste. The current DOE definition of HLW uses the qualitative phrase "in concentrations requiring permanent isolation." Because this definition could lead to several different interpretations, it may need reexamination. Also, any concentration-based definition may need to be reexamined in view of the fact that the Nuclear Regulatory Commission (NRC) source-based definition remains part of U.S. Code. Finally, it may be desirable to arrive at a single, consistent definition of HLW and other waste categories that is adopted by DOE, NRC, and the Environmental Protection Agency (EPA) and is acceptable to State agencies and public interest groups. However, irrespective of definition, the waste must meet EPA disposal standards that have to be reissued; the definition and standards are interrelated.

Repository Delays and Contingency Planning

DOE's Five-Year Plan is predicated in part upon the availability, starting about 2010, of a deep geologic repository for disposal of HLW, as mandated by Federal legislation. In accordance with this thinking, DOE is moving forward, at three of four sites that have HLW, with vitrification facilities for converting HLW from a liquid to a glasslike solid in a form acceptable for repository disposal. This strategy has the major advantage of reducing the potential threat to public health and the environment, in the short term, that is posed by more mobile tank waste, albeit at some increased occupational risk. However, more consideration must be given to facilities and requirements for storing solid waste if the repository opening is delayed.

For several decades, or even longer, de facto, on-site, monitored, retrievable storage of vitrified waste should not be technically prohibitive, provided vitrification goes well.[108] However, the institutional controls and monitoring needed for such storage require further attention. There appears to be no substantial contingency planning underway to allow for the possibility that vitrification might not succeed or might encounter major delays; the calcination work at the Idaho National Engineering Laboratory (INEL), which produces a powdery solid that is stored in bins with a lifetime of 400 to 500 years is an alternative that could be examined. The political trade-offs associated with planning for various contingencies must also be considered. For example, shipment of canisters with vitrified HLW to a geologic repository may be opposed by some along the transport route; on the other hand, long-term on-site storage of those waste canisters may not be acceptable to residents and officials of the State in which the site is located. In addition, changing from the current policy of building a deep repository in favor of monitored retrievable storage at the weapons sites would require extensive study and debate. These issues could be scrutinized further in the Programmatic Environmental Impact Statement (EIS) that DOE now has underway.

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[106] Personal communication during visit to Savannah River Site, Oct. 26, 1990.

[107] Ibid.

[108] European countries plan to allow their vitrified high-level waste to cool on-site for 50 years before further action is taken. The benefit of letting the waste cool (i.e., undergo some radioactive decay prior to repository disposal) merits consideration in the United States, which has not planned for such a long cooling period but may, in fact, be accommodating to one.

Urgency of High-Level Tank Waste Treatment

The urgency of solidifying high-level tank waste is difficult to quantify. For example, although DOE generally asserts that HLW currently stored in tanks at Hanford, Savannah River, Idaho, and West Valley poses no imminent threat to public health, current or potential groundwater contamination due to tank leakage is a matter of debate. Concerns about the possibility of tank explosions with ensuing large releases of radioactivity also continue to arise. Accurate characterization will require time and money—perhaps a decade and hundreds of millions of dollars—if current regulatory guidelines are adhered to. The characterization process might be speeded up by more focused sampling and attention to suspected environmental pathways.

Current DOE plans indicate that vitrification of liquid waste from double-shell tanks at Savannah River will begin in FY 1992 or 1993, followed by vitrification of Hanford double-shell tank waste commencing in FY 1999. Decisions about the treatment or disposal of single-shell tank waste at Hanford have been deferred. The tri-party agreement calls for closure of single-shell Hanford tanks during the period 2005 to 2018; the agreement also calls for the removal of all pumpable liquid waste from these tanks by 1996 (42). A General Accounting Office (GAO) report advises that this latter date should not deter DOE from removing the liquid sooner, if possible, given GAO's conclusion that DOE's current monitoring efforts do not provide sufficient data to adequately trace the migration of leaks or to fully assess their effects (42). GAO also advises placement of new ground cover material over the tank farms to slow water drainage through the soil. The major concern is the danger of contamination of groundwater and the Columbia River by leaking high-level tank waste.

At Hanford, priority was given to early treatment of liquid HLW in double-shell tanks, in response to a number of factors, possibly including the relative ease of treatment of double-shell waste compared with single-shell waste; the less mobile condition of single-shell waste; and the fact that the double-shell tanks are required for new waste storage. This priority is now codified in the tri-party agreement. While it is important to move ahead with a treatment system for the double-shell tank waste, it is also important to give attention to the single-shell tank problem and to reach a decision on how to improve conditions of waste storage there as soon as possible. At a December 1989 meeting of the National Academy of Sciences Panel on Hanford Single-Shell Tanks, panel members urged DOE and Westinghouse-Hanford to take a more systematic overall approach to exploring alternatives for treatment and disposal of single-shell tank waste rather than simply focusing on specific tasks, such as taking core samples, without any concept of the "big picture" for treatment and disposal. The panel also called for more evaluation of the potential for tank explosions due to the ferrocyanide that had been added to some single-shell tanks, as well as a determination of other tank contents that might constitute an explosive hazard. If this evaluation should reveal the possibility of tank explosion, immediate corrective action would have to be considered. Indications, based in part on DOE statements to date, are that the possibility of explosions involving ferrocyanide will be of greater concern during treatment operations than during storage.

More recently, reports of the presence of hydrogen gas in some of the HLW tanks at Hanford have raised the possibility of fires or explosions. The matter is under more intensive study by DOE following a number of oversight investigations and hearings in 1990. This situation increases the urgency of proceeding with the solidification of high-level tank waste. However, the trade-offs between moving ahead with dispatch and moving ahead too precipitously require careful consideration. In early 1991, Secretary of Energy Watkins indicated that a two-year delay in the start of construction of the Hanford Waste Vitrification Plant was needed; two reasons were to complete a risk assessment and to develop more data on the contents of the tanks to ensure safe pretreatment. Such a delay would require modification of the Tri-Part Agreement.[109]

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[109] "Secretary Delays Construction of Hanford Waste Vitrification Plant," *Weapons Complex Monitor*, Feb. 25, 1991, p. 11.

Technologies for High-Level Waste Treatment

Two technologies are central to DOE's plans for treatment of liquid high-level tank waste over the next decade: 1) vitrification of the "high-level" component of the waste with borosilicate glass, followed by placement in canisters and disposal in a deep repository, and 2) immobilization in grout or concrete of the "low-level" component of the waste, followed by on-site disposal either at or near the surface. Both of these technologies require major financial investments, especially vitrification. It is important that technical work be performed well and monitored carefully.

Vitrification of the HLW component is scheduled to commence in the Defense Waste Processing Facility (DWPF) at Savannah River in 1992 or 1993. The technology will have to be carefully demonstrated over a period of time, first with cold runs (i.e., with no radioactive waste). These cold run tests began in the fall of 1990. Careful balance is required between the need to move as rapidly as possible in getting high-level tank waste into the more stable vitrified form, and the need to proceed carefully and cautiously. If all goes reasonably well at Savannah River, the Hanford Waste Vitrification Plant (HWVP) should be less problematic because it will use a technology similar to that of the DWPF.

The operation of grout facilities at both Savannah River and Hanford could reduce the volume of high level tank wastes to be managed in the future. Grout or concrete has the advantage of being a solid form, in contrast to current tank waste liquids and sludges. However, given the concerns that have been raised about treating some fraction of the high-level tank waste in a "low-level" manner, some questions concerning this practice must be resolved. A key question is how long will the grout last (i.e., keep radioactive or hazardous components contained)? DOE may need to investigate the lifetime of these waste forms more extensively.

Rethinking the Waste Form and Package

DOE has decided to use a waste form and package for the disposal of vitrified HLW that involves using borosilicate glass and relatively thin-walled (about 1-centimeter-thick) stainless steel canisters. Whereas this approach was chosen to assure a lifetime range of several hundred to 1,000 years, the canister itself is not expected to last the 10,000 or more years required to isolate the long-lived transuranic and other radionuclides from the environment. Therefore the current approach provides for long-term integrity to be ensured in large part by the integrity of the deep geologic repository.

In contrast, Sweden places more reliance on the waste package to ensure that radionuclides will not escape into the environment. Plans call for the Swedish waste package to be thick walled (about 10 centimeters) and for the copper canisters to be filled with either molten lead or copper surrounding the spent fuel. A National Academy of Sciences panel that reviewed the Swedish plans believes that, in this manner, canister lifetimes of 1 million years or more can be achieved (28). This means that less reliance has to be placed on the geologic repository.

The need to achieve a 10,000-year or 100,000-year lifetime for waste isolation in a repository has created a difficult regulatory problem. EPA's HLW disposal standards were struck down by a court in part because some controls were not deemed to assure control for a sufficient length of time (16). Also, there is the possibility that stricter radiation protection standards may be needed in response to the findings of increased risks of cancer from radiation (29). Finally, if a deep geologic repository for HLW disposal is delayed for a long time, and monitored retrievable storage were required during that time, a waste package with a long design life could be useful.

Given the delays in repository development in the United States, it might be useful to review storage and disposal options for defense HLW with particular attention given to strengthening the engineered barrier performance of the waste package.[110] Although some elements of DOE's HLW management strategy (such as the DWPF vitrification plant at Savannah River) may be too far along to change, others (such as the HWVP) may not be. Also, since DOE's canister must fit in the same NRC-approved container as commercial spent fuel before being placed in the repository, the canister design might not have to be changed; instead, the overpack container could be modified to provide additional barrier performance.

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[110] In July of 1990 the National Research Council issued a report that indirectly supports this statement (30): "... there are a number of unresolved issues in the U.S. radioactive waste disposal program, as well as (and in part because of) high levels of uncertainty and public unease about the performance of the repository ... the proper response to uncertainty is greater knowledge and flexibility, as well as redundancy of barriers to nuclide transport."

A key question to be considered is whether the major additional cost of proceeding with engineered barriers is justified by the benefits to be derived. Another question is whether current performance assessment methodology for the combination of engineered barriers and repository allow assessments to be made in which one can have confidence. This may depend on whether knowledge of interaction between the engineered barrier and the repository environment is sufficiently advanced so that a barrier can be designed that will perform its function for the required period of time.

The choice of borosilicate glass as the waste form for vitrification of HLW is consistent with the waste form selected in other countries. OTA found that a high level of confidence in this choice was held by DOE and its contractors; however, this view is not shared by all. Concerns have been raised about the long-term performance of borosilicate glass in the Yucca Mountain repository environment, the adequacy of the scientific program to demonstrate that borosilicate glass will retain defense HLW for the necessary duration,[111] and the lack of adequate R&D on second generation waste forms after DWFP.[112]

Producing a qualified waste form from the wide range of input waste feed to the vitrification process is a challenging technical assignment. The development of a theoretical framework with which to predict long-term waste form performance appears to be an ongoing process and DOE, in cooperation with the regulatory agencies, will be participating in this process for many years to come.

Waste Form for the Idaho National Engineering Laboratory

Cost reduction appears to be a major factor in the search for a waste form other than borosilicate glass at INEL; each canister of vitrified borosilicate HLW is very expensive to produce and dispose of in a repository (50). If more waste can be loaded onto the matrix by the use of glass-ceramic instead of borosilicate glass, costs for immobilizing the HLW at Idaho might be reduced by billions of dollars.

Idaho also has 25 years of experience in calcining HLW. Currently, the HLW calcine at INEL is stored in stainless steel bins within reinforced concrete vaults having design lifetimes of 400 to 500 years. The possibility of hardening the calcine within the existing storage bins could be an alternative under consideration.

The INEL waste form decision represents an opportunity to reexamine this area in light of what has been learned since the decision in favor of borosilicate glass a decade ago. Such reexamination could include economic, environmental and political factors. An independent technical review panel might be useful in this regard if it had the resources to do the level of evaluation needed.

Releases to the Atmosphere

Nuclear reactors, reprocessing plants, and facilities such as evaporators and calciners for treating HLW sometimes release radioactive or hazardous materials to the atmosphere. Through the introduction of air filters and other off-gas handling equipment, releases of radionuclides have been greatly reduced, but not totally eliminated, since the early days of the weapons program. In addition to releases from routine operations, concern persists about potential releases during accidents such as HLW tank explosions of the kind that occurred in 1957 in the Soviet Union. Air emissions, including radioactivity, from DOE sites are subject to National Emissions Standards for Hazardous Air Pollutants (NESHAPS)[113] promulgated by EPA under the Clean Air Act.

Unlike groundwater, the air exposure pathway of the offending materials is direct and known. At the Office of Technology Assessment (OTA) Health Effects Panel Workshop in January 1990, several panelists stated that they believed airborne release of both radioactive and hazardous materials to be a greater potential health threat than groundwater contamination. Further, they pointed out that the Resource Conservation and Recovery Act (RCRA) and the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) regulations focus attention on groundwater contamination but ignore air releases. Setting standards for the release of radionuclides to air has been the object of contention between NRC and EPA (33), and the monitoring of emissions presents some technical difficulties. Although EPA has authority to set air release standards for radioactivity from DOE sites, implementation and enforcement remain with DOE. It may be useful to pay more attention to regulating air emissions, to implementing and enforcing air release standards, and to monitoring DOE activity in this area.

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[111] Matusek, J.M., "Issues of Glass Waste-Form Reformance: Summary," Waste Form/Repository Meeting, U.S. Department of Energy, Dec. 20, 1990, p. 1.

[112] Ewing, R., personal communication to R.P. Morgan, March 5, 1991.

[113] National Emission Standards for Hazardous Air Pollutants, 40 C.F.R. §61 (1990).

Future of the PUREX Plant at Hanford

In December 1988, the PUREX fuel reprocessing plant at Hanford was shut down in mid-campaign due to a low steam pressure condition. The plant has caused concern because of its age, the large amounts of hazardous and radioactive wastes it produces, past atmospheric releases, and continued release of liquid effluents to the soil even in its shutdown condition. In December 1989 the plant was restarted for a short time to stabilize the situation by flushing out material that had settled in pipes and other equipment during the sudden shutdown. After this stabilization run, DOE had planned to restart PUREX in late 1990 to reprocess the backlog of spent defense fuel over a 5-year period and then permanently to close the facility. However, a decision was made in 1990 not to restart PUREX for at least 2 years but to prepare an EIS and evaluate options for handling the stored fuel.

The decision not to restart PUREX may have been reached for a number of reasons, including: 1) the U.S. plutonium stockpile is widely reported to be sufficient; 2) citizen groups and state officials had increasingly raised questions and expressed concern about environmental impacts of operating PUREX; 3) regulatory constraints imposed by RCRA had already shut down the plant and there was also the threat of pending legal action if restart was attempted; and 4) outside independent analysis coupled with DOE's own work suggested that encapsulation and storage of spent N-reactor fuel could be an alternative to reprocessing with environmental benefits.

The future of PUREX will continue to be an issue of intense public concern as well as requiring sound technical analysis. It will be a challenge for DOE to resolve while actively involving the public in the EIS process.

Waste Minimization; Tritium Production; International Cooperation

The radioactivity of HLW generated from reprocessing spent fuel and irradiated uranium targets is strongly related to weapons material production requirements. Within current production practice, it will be difficult to reduce HLW other than by reducing production. However, it may be possible to produce tritium without producing HLW if no reprocessing of the spent driver fuel elements is performed. There is no minimization of radioactivity if such a change in operations were to be adopted; to a first approximation, the total radioactivity associated with the fission process should be the same, whether the radionuclides are contained in the spent fuel elements or released from those elements and contained in waste tanks, or eventually, in glass logs.

Hazardous waste and certain types of radioactive and mixed waste other than HLW might well be reduced by technological improvements to reprocessing. The U.S. decided in the 1970s not to pursue reprocessing of commercial nuclear fuels. Other nations may have acquired certain expertise in reprocessing that might prove useful to DOE's efforts at waste minimization. DOE has already supported several important programs in international technology exchange. Since the DOE waste minimization program is currently in a very early stage, its design could profit by a wide range of input. Learning from international experience and expertise should be a strong element of the DOE effort.

Scenarios for Future HLW Production

HLW is an inevitable consequence of the fission process that occurs in current nuclear weapons production practices. At present, no DOE weapons production reactors are operating. This pause in reactor operations provides an opportunity to pursue cleanup at the Weapons Complex during a time of reduced levels of HLW generation. The Department of Energy has recently begun to prepare an Environmental Impact Statement of its plans for modernizing the Weapons Complex. Such an analysis should provide valuable insights and help DOE in its efforts to focus greater attention on the environmental consequences of various production scenarios.

In January 1991, DOE issued a Reconfiguration Study for the Weapons Complex which appears to represent a useful step towards facilitating the PEIS process. In that study, alternative configurations were outlined for four different production scenarios, ranging from 15 to 70 percent of current production levels.[114] Among the issues that could usefully be addressed in the PEIS on modernization is how effective a waste minimization program could be accomplished under each of the alternative configurations.

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Chapter 2
Managing Transuranic Waste at the DOE Nuclear Weapons Complex

SUMMARY

Overview

It has been only 50 years since elements heavier than uranium—hence, the term transuranic—were created. These elements do not occur in nature and were first produced in nuclear reactors as part of the World War II effort by the United States to develop the atomic bomb. An isotope of one of these elements, plutonium-239, has physical and nuclear properties that make it a desirable material for atomic weapons—only a few kilograms or tens of kilograms are required. Plutonium was the explosive material in the bomb dropped on Nagasaki. It is found in the "triggers" of tens of thousands of modern thermonuclear weapons in the arsenals of the United States and the Soviet Union. Whereas in the early 1940s, scientists working on the wartime Manhattan Project struggled to produce microgram quantities of plutonium-239, tons of it exist today.

Threats to human health from plutonium and other transuranics do not arise solely from the possibility of their use in a thermonuclear conflict. Most transuranic radionuclides decay by emitting helium nuclei—that is, alpha particles, a heavily ionizing form of matter. These alpha particles make plutonium toxic to humans in very small quantities when inhaled or ingested. Furthermore, some transuranic radionuclides are very long-lived and tend to persist rather than decay rapidly to other nuclides. A principal concern is plutonium-239, which has a half-life of 24,400 years; this means that half of the plutonium-239 in existence in 1990 will still exist in the year 26,390.

Plutonium-239 is produced via capture of neutrons by uranium-238 in nuclear reactors. This process goes on continually in commercial nuclear power reactors, as it did in the Hanford reactors for weapons production purposes during and after World War II. While in the U.S. commercial sector, almost all of the plutonium is contained within the solid structure of spent fuel elements removed from reactors, in the defense sector, plutonium is spread more widely in the environment because fuel elements and targets have been reprocessed, by using aqueous and organic liquids, to unlock and separate the plutonium for recovery and incorporation into weapons. Reprocessing has resulted in contamination by plutonium of soil and sediments in the vicinity of certain sites in the Nuclear Weapons Complex. In addition, contamination of workers and workplaces from various plutonium handling and machining operations is a constant concern. One example of this is the report in 1990 that enough plutonium had accumulated in the ducts at the Department of Energy Rocky Flats Plant to fuel several nuclear weapons.

Transuranic (TRU) waste arises in the U.S. defense program primarily as a consequence of reprocessing plutonium-bearing fuel and irradiated targets, and from operations required to prepare the recovered plutonium for weapons use. TRU waste includes TRU metal scraps as well as glassware, process equipment, soil, laboratory waste, ion-exchange resins, clothing, filters, glove boxes, and paper products contaminated with TRU materials.

Until 1970, TRU waste was handled in a manner similar to low-level waste (LLW): it was dumped into trenches or pits and covered over or buried; such waste is referred to as *buried TRU waste*. Pre-1970 practices have resulted in great uncertainty in the estimates and location of buried TRU waste and TRU-contaminated soil. Subsequently, in accordance with a 1970 Atomic Energy Commission (AEC) decision, TRU waste was stored, usually in metal drums, in a manner to permit easy recovery and treatment, because of the growing realization that long-lived radionuclides such as plutonium-239 require more careful handling, storage, and long-term disposal than previously recognized; such waste is referred to as *retrievably stored TRU waste*. In general, the Department of Energy (DOE) views retrievably stored and yet-to-be-generated waste as a *waste management* problem, whereas buried waste is an *environmental restoration* problem; the two may require different technological, evaluative, and administrative approaches. Since the mid-1970s, plans for long-term disposal of TRU waste have centered upon the availability of a deep geologic repository, paralleling earlier thinking about disposal of high-level waste (HLW).

DOE's policy is that retrievably stored and yet-to-be-generated TRU waste will be disposed of in a geologic repository. The Waste Isolation Pilot Plant (WIPP) near Carlsbad, NM, was authorized by Congress in 1980 to serve as a research and development facility for disposal of such TRU waste in bedded salt. Upon completion of the test phase, WIPP might then serve as the first deep geologic repository for defense TRU waste. WIPP has now been built. To date, no waste packages have been placed in WIPP. A positive decision by Secretary of Energy James D. Watkins on DOE's readiness to proceed with the experimental phase was made in June 1990. The earliest date for disposal of TRU waste in the WIPP facility on a regular, operational basis is 1995. Other scenarios foresee WIPP opening much later.

Data and Projections

DOE collects information on various waste types in its Integrated Data Base (IDB), which is updated annually. According to the 1989 IDB (77), both retrievably stored and buried TRU waste are distributed over six sites: the Idaho National Engineering Laboratory (INEL) has 61 percent of the retrievably stored waste, and Hanford has 57 percent of the buried waste by volume. The volume of buried TRU waste is estimated to be three times that of retrievably stored TRU waste.[1] A seventh site, the Rocky Flats Plant, also has been storing TRU waste since late 1989 when the State of Idaho refused to accept further shipments. Most of the stored TRU waste by volume is *contact-handled*; that is, its radioactivity is sufficiently low that it is considered safe for workers to manipulate the drums. Smaller volumes of TRU waste at Oak Ridge and other sites have radioactivity levels sufficiently high, due to fission products mixed with the waste, to require that waste packages be handled remotely—hence, the term *remote-handled* waste.

The 1989 IDB (77) projects a large increase in radioactivity associated with total stored TRU waste by the year 2013, growing to 3.5 times the 1988 value (74).[2] Much of the growth appears to be associated with activities at the Savannah River Plant. The scaledown in growth indicated by the projections in the 1988 and 1989 IDBs could reflect some downward adjustment in weapons material requirements due to the improved arms control outlook. Nevertheless, existing projections indicate a growing burden of TRU waste to be managed over the next 25 years.

The Definition of TRU Waste

Transuranic (TRU) waste is defined as waste contaminated with alpha-emitting transuranium radionuclides with half-lives of more than 20 years and concentrations higher than 100 nanocuries per gram. This limit was raised from 10 nanocuries per gram in 1984. It permits DOE to reclassify and dispose of some of what used to be TRU waste as LLW. However, regardless of definition, the waste must meet appropriate disposal standards. At present, Environmental Protection Agency (EPA) standards for disposing of plutonium waste are either nonexistent or in need of review, and important elements of EPA radiation protection standards for disposal of TRU waste also need to be reissued.

Buried Transuranic Waste

Characterization of, and strategies for, handling buried TRU waste or remediating TRU-contaminated soil are in the very early stages. Thus, knowledge of buried waste sites and soil contamination is far from complete. A National Academy of Sciences panel is monitoring efforts by DOE and its contractor, EG&G-Idaho, to determine how to deal with buried TRU waste at INEL. Among the issues under consideration are better delineation of waste migration; the risks and benefits associated with in situ treatment of waste versus digging it up and treating it; and sites for disposal of the waste, if and when it is retrieved. Remediation of the Subsurface Disposal Area (SDA) at INEL where buried TRU waste is located has been governed by a Consent Order and Compliance Agreement (COCA), based on the Resource Conservation and Recovery Act[3] (RCRA), involving EPA Region X, DOE, and the

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[1] IDB estimates of buried TRU waste are subject to considerable uncertainty. Stored TRU waste estimates should be somewhat more reliable, although large variations occur from year to year. In general, the IDB does not show ranges of estimates to provide some measure of their uncertainty.

[2] A similar projection made with data from the 1988 IDB shows a growth to almost eight times the 1987 value. However, the most recent projection in the 1990 IDB indicates a growth by the year 2013 to only 1.9 times the 1989 value.

[3] Pub. L. No. 94-580, 90 Stat. 2795 (1976) (codified as amended at 42 U.S.C. 6901-07 (1982); 42 U.S.C. 6911-16, 6921-31, 6941-49, 6951-54, 6961-64, 6971-79, 6981-86 (1982)); amended by Solid Waste Disposal Act Amendments of 1980, Pub. L. No. 96-482, 94 Stat. 2334 (1980) (codified at 42 U.S.C. 6901-91(i) (1982)); Hazardous and Solid Waste Amendments of 1984, Pub. L. No. 98-616, 98 Stat. 3221 (codified at 42 U.S.C. 6924 (1984)).

U.S. Geological Survey (USGS). An interagency agreement based on the Comprehensive Environmental Response, Compensation, and Liability Act[4] (CERCLA) addressing remediation of nonoperating disposal sites is awaiting Secretary Watkins' approval. Studies of alternative remediation techniques will undoubtedly continue for some time.

Some technologies used for cleanup of buried TRU waste sites could prove to be similar to those used for LLW sites. However, EPA disposal requirements equate TRU waste with HLW and both are currently slated for disposal in deep geologic repositories. A major effort is still required to sort out which technology will be useful and cost-effective for each waste situation, both for remediation of buried TRU waste sites and for treatment of stored TRU waste. The presence of hazardous components mixed with radioactive materials must also be taken into account.

In situ vitrification (ISV) is being investigated for use in immobilizing radionuclides and hazardous materials in contaminated soil or in buried drums. Electrodes placed in the soil melt and then harden the soil and its contents into a glasslike substance. This technology, while promising, also has limitations, including high operating (energy) costs, applicability to relatively shallow soil depth and dry soil, and possible worker hazards from strong electric fields and from generated vapors. Economic analyses of the projected costs of ISV as a function of the amount and nature of material to be immobilized are necessary. The first full-scale ISV test has been underway in a waste crib at Hanford that is a high-priority cleanup site. Demonstration tests are also being carried out at INEL.

One problem being studied at INEL in connection with buried TRU waste is the development of plumes of volatile organic compounds beneath the surface that might accelerate the migration of radionuclides to groundwater. Efforts are underway to characterize the carbon tetrachloride plume under the SDA and in the vadose zone. A vapor vacuum extraction process for removing organic vapor from subsurface areas is also being tested.

Storage and Treatment of Retrievably Stored Transuranic Waste

Currently, stored TRU waste is usually found in 55-gallon drums placed on concrete or asphalt pads, awaiting assay, treatment, and certification for shipment to and disposal at the WIPP. The waste in these drums is soluble, respirable, and not generally fixed in an immobilized matrix. The drums were designed for a lifetime of 20 years, and some drums have held TRU waste for that period. Six of eight drums retrieved from a pad at INEL in late 1989 had rust holes up to 4 inches in diameter; no leakage is reported to have occurred because the waste was contained in internal polyethylene bags. The duration of waste drum storage for TRU waste mixed with contaminants considered hazardous under RCRA is also limited by EPA land disposal restrictions.

According to the 1989 Five-Year Plan, six new DOE facilities were scheduled to begin operation during FY 1992-99 for processing, treating, and certifying retrievably stored or newly generated TRU waste for shipment to WIPP. Among the technologies to be used in one or more of these facilities are shredding, incineration, compaction, and immobilization in grout or concrete. The first facility that was scheduled to begin operation, the Processing Experimental Pilot Plant (PREPP) at INEL, has encountered both technical and regulatory problems and its future is uncertain. PREPP incorporates rotary kiln incineration and an elaborate off-gas cleanup system to reduce radioactive and hazardous gas releases. Although incineration as a treatment technology has received considerable attention from EPA, it has generally encountered considerable public opposition.

A short-term problem facing DOE is what to do about the mixed TRU waste at the Rocky Flats Plant. The State of Idaho stopped accepting Rocky Flats waste in late 1989, and Colorado, using its RCRA authority set a limit of 1,601 cubic yards on the amount of mixed TRU waste that can be stored. That limit could be exceeded in 1991 or 1992. A further problem involves a Federal District judge's April 1990 ruling reclassifying some Rocky Flats residues as waste. DOE and State officials have been negotiating an Order of Consent to reflect the court ruling; the conditions of the order will then be incorporated as part of the permit application for the facility. DOE has also submitted a permit request seeking approval for the operation of a volume reduction unit (or supercompactor) to compact certain existing wastes and improve current capacity.[5]

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[4] Pub. L. No. 96-510, 94 Stat. 2767 (1980) (codified as amended in scattered sections of the I.R.C. and 33, 42, and 49 U.S.C.). Any reference to CERCLA made throughout this paper should be construed as a reference to the 1980 statute, as amended by the 1986 Superfund Amendments and Reauthorization Act and codified at 42 U.S.C.A. 9601-11050 (West 1983 and Supp. 1990).

The Waste Isolation Pilot Plant

As of early 1991, the experimental phase at WIPP still had not begun, and some obstacles remained to be overcome. In 1990 legislation was proposed in Congress to withdraw land from the public domain for WIPP use but it did not pass. The legislative debate on land withdrawal provided an opportunity for those with concerns about WIPP to express them and to attempt to build into the legislation certain conditions to which DOE must adhere. Among the concerns expressed were the need for compensation to the State of New Mexico in the form of funds for highway construction to bypass certain areas; limitation of the amount of waste that can be placed in WIPP until DOE can demonstrate that EPA's disposal and no-migration standards for mixed TRU waste can be met; resolution of certain technical and safety issues related to the experiments; and debate about the merits of providing independent, non-DOE regulation of the WIPP facility. However, DOE bypassed the legislative route and land withdrawal was accomplished administratively in early 1991, even though the Department had stated that it would prefer not to pursue this course of action.

In 1987, EPA standards for geologic disposal were remanded by the court and may not be in effect when the WIPP experimental phase begins. If so, DOE might have to remove the waste at some future date either to comply with new standards when they are issued or because tests fail to support a determination that the standards can be met. Alternatively, DOE could defer moving waste to WIPP, but then it would continue to be stored on sites in States where it is not welcome. The General Accounting Office (GAO) has called for more contingency planning on DOE's part for waste storage. GAO has also suggested that Congress consider placing some restrictive requirements, such as limiting the amount of waste that can be emplaced prior to issuance of EPA disposal standards, in any legislation that may be proposed to withdraw public lands for the WIPP repository. The State of New Mexico has agreed to DOE conforming with the disposal standards vacated by the courts until new standards are issued.

The generation of gas in drums containing TRU waste, in the form now planned for placement in WIPP, is a problem that must be addressed. Some have used currently available information on gas generation rates to predict that within 50 to 100 years after disposal in WIPP, the buildup of gas due to corrosion of the carbon steel drums and to radiolytic and biological degradation of organic materials could reach pressures at which salt might be fractured or pushed back and radioactive or hazardous materials might escape from the repository. Although DOE and its contractors are studying the problem and hope to obtain additional information from the initial tests at WIPP to supplement earlier information, some experts feel that modifying the current waste form to either reduce or eliminate gas generation will be necessary. By treating the waste with methods ranging from compaction to immobilization, to reduce or eliminate gas generation, uncertainty concerning long-term repository behavior and the vulnerability of the repository to both undisturbed and human intrusion scenarios could be lessened. However, treating TRU waste, particularly by methods that should be most effective in eliminating gas generation (i.e., incineration or vitrification) would require a substantial increase in funding as well significant changes in DOE waste management plans and facilities, would cause commensurate delays, and could increase worker radiation exposures.

Interested parties disagree on the value of the WIPP experimental phase as it is presently defined. Questions have arisen as to whether certain experiments will provide the information required to determine whether EPA disposal standards can be met, or whether some experiments might be performed more expeditiously outside of WIPP. In addition, although a task force created by DOE is studying alternative forms, as of late 1990, the initial experiments planned for WIPP did not appear to include certain alternative waste forms that would generate less gas than the existing preferred form. WIPP was authorized by Congress as a research and development facility to demonstrate safe disposal of TRU waste; yet, as it is now constituted, the program proposed by DOE does not appear to have convinced its critics that all important concerns have or will be addressed.

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[5] F. Dowsett, Colorado Department of Health, personal communication, Jan. 4, 1991.

Standards, Regulations, and Oversight

EPA disposal standards represent the primary line of defense for public health and safety against radioactivity from TRU waste. These standards, promulgated in 1985, are being reformulated because they were vacated in June 1987 following a court challenge. New standards were expected to be proposed by EPA in late 1990 (they were not) and finalized by 1992. Concern has been expressed about DOE's ability to meet these standards without changing the waste form or using engineered barriers, particularly under human intrusion scenarios. DOE does not expect to be in a position to demonstrate compliance until the performance assessment is completed in 1995; it views the WIPP experimental phase as not requiring such compliance because the waste for the experiments will be retrievable. EPA concurs with this position.[6] Efforts to weaken the standards have been opposed by the Environmental Evaluation Group (EEG), the federally mandated WIPP oversight group associated with the State of New Mexico.

Independent technical oversight of WIPP by EEG is valuable to the process of developing a viable disposal facility and enhances DOE's credibility. Although other oversight mechanisms utilized by DOE provide useful inputs, EEG's full-time, long-term presence, permanent staff and consistent resources are unique elements that contribute to its effectiveness. Also of importance is EEG's ability to remain independent of DOE, even though its funding comes from the Department.

Much TRU waste is mixed (radioactive and hazardous) waste to which RCRA regulations apply. DOE has requested a no-migration variance for waste to be placed in WIPP, arguing that hazardous waste will not move off-site. In April 1990, EPA proposed to grant DOE's request for the experimental phase only, with a decision on the operational phase to be made later. EPA approval of the WIPP no-migration petition for the test phase followed on November 1, 1990, subject to several conditions, including testing of gases from each of the waste drums to be placed in WIPP during the test phase.

With regard to mixed TRU waste stored at DOE facilities, storage or disposal of such waste is generally prohibited by EPA under land ban restrictions unless the waste has been treated in an EPA-approved manner. However, in light of the limited capacity available nationwide to treat mixed TRU waste, EPA issued a 2-year variance on June 1, 1990, to provide sufficient time for building the capacity required to treat the mixed waste generated and stored at facilities in the DOE Weapons Complex. As a result, DOE is not required to comply with the treatment and disposal requirements applicable to mixed waste under RCRA until 1992.

Research and Development, Waste Minimization, Transmutation

The DOE Applied Research, Development, Demonstration, Testing, and Evaluation Plan (47) singles out three specific areas for TRU (retrievably stored or newly generated) waste management: better waste treatment to meet WIPP certification requirements; disposal options for waste not certifiable for WIPP; and better characterization of RCRA components in waste for certification. The plan lists a number of technologies that might prove useful for the buried waste remediation effort but does not evaluate them. A process for doing so may be underway in connection with updates of the Five-Year Plan.

Minimizing waste from plutonium manufacturing and processing can reduce the amount and radioactivity of TRU waste. Among the opportunities for such minimization, according to DOE, are forming blanks closer to final size, improving machining precision, using robotics and automation in handling, and improving plutonium recovery by using fewer chemicals and producing less plutonium-bearing waste. However, to date, DOE is not very far along in the TRU waste minimization area. The most substantial TRU waste minimization has likely been a result of the shutdown of operations at Rocky Flats since late 1989.

Transmutation is believed by some to be an attractive concept for minimizing TRU waste.[7] It involves separating (partitioning) long-lived TRU and other radionuclides from the waste stream for recycling and subsequent conversion (transmutation) to shorter-lived radionuclides by nuclear reactions in a reactor or an accelerator, thereby reducing the time required for the radioactive wastes to decay

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[6] This position is inconsistent with the parallel case of the Yucca Mountain, NV, HLW repository. There, the NRC requires demonstrated compliance with long-term disposal standards before construction can begin.

[7] The phrase actinide conversion is used by some to characterize this process.

Box 2-A—Definition of Transuranic Waste[1]

Transuranic (TRU) Waste is defined in Department of Energy (DOE) Order 5820.2A (58) as follows:

> Without regard to source or form, waste that is contaminated with alpha-emitting transuranium radionuclides with half-lives greater than 20 years and concentrations greater than 100 nCi/g at the time of assay. Heads of Field Elements can determine that other alpha contaminated wastes, peculiar to a specific field site, must be managed as transuranic waste.

DOE Order 5820.2A (58) also defines two subsets of packaged TRU waste as follows:

> *Remote-Handled Transuranic Waste*. "Packaged transuranic waste whose external dose rate exceeds 200 mrem per hour. Test specimens of fissionable material irradiated for research and development purposes only and not for the production of power or plutonium may be classified as remote-handled transuranic waste."
>
> *Contact-Handled Transuranic Waste*. "Packaged transuranic waste whose external surface dose rate does not exceed 200 mrem per hour."

[1] Ci/g = nanocuries per gram (1 nanocurie = 10^9 curies); mrem = millirem.

to acceptable levels after disposal. One reason given for continued funding of the Fast Flux Test Facility at Hanford is for just this purpose. However, transmutation is still in the research stage; it is not a part of recent DOE 5-year waste management operations plans, nor is it likely to prove useful for TRU waste management over the next 10 years. These are also significant obstacles to transmutation becoming a major factor in TRU waste management over the long-term.

TRANSURANIC WASTE AT DEPARTMENT OF ENERGY SITES

Definition and Background

In the United States, TRU waste is largely unique to the defense program and arises primarily through reprocessing of plutonium-bearing fuel and irradiated targets, and from the many operations required to manufacture plutonium in the form and grade required for use in nuclear weapons.[8] Some TRU-contaminated waste is also generated by remedial action projects as well as by decommissioning and decontamination activities. TRU waste includes metal, glassware, process equipment, tools, soil, laboratory waste, rubber gloves, ion-exchange resins, filters, clothing, rags, and paper products (55,77). Among the TRU waste forms are absorbed liquid or sludge, combustibles, dirt, gravel or asphalt, and concreted or cemented sludge. Much TRU waste is mixed waste, containing both radioactive and hazardous components. Box 2-A contains current definitions of TRU waste.

TRU waste clearly is managed much more carefully now than it was 20 years ago. Until that time, it had been handled in a fashion similar to LLW—dumped into trenches or pits and covered with earth. In 1970 the Federal Government began to store TRU waste for easy retrieval rather than burying it in pits and trenches (77). One reason for the earlier lack of rigor in handling certain forms of transuranics might have been that the radioactivity associated with items such as contaminated clothing was not very large compared with the radioactivity associated with liquids from reprocessing plants.

According to table 2-1, the TRU radionuclide that is preferred as a nuclear weapons material, plutonium-239, has a half-life of 24,400 years. Plutonium-239 is toxic in very low concentrations, with the primary health threat coming from the inhalation of material that lodges in the lungs and emits heavily ionizing alpha particles that are readily absorbed and could produce carcinogenic effects. The staying power of the long-lived, radioactive transuranics, coupled with their toxicity when inhaled or ingested, necessitates their careful handling, treatment, and disposal.

Table 2-1—Some Transuranic Radionuclides and Their Half-Lives

Element	Atomic weight	Half-life (years)
Neptunium	237	2.14×10^6
Plutonium	238	86
	239	24,400
	240	6,580
	241	13.2
	242	3.79×10^5
Americium	241	458
	243	7,950
Curium	244	17.6
	245	9,300

SOURCE: M. Benedict, T.H. Pigford, and H.W. Levi, *Nuclear Chemical Engineering*, 2d ed. (New York: McGraw-Hill, 1981), pp. 976-977.

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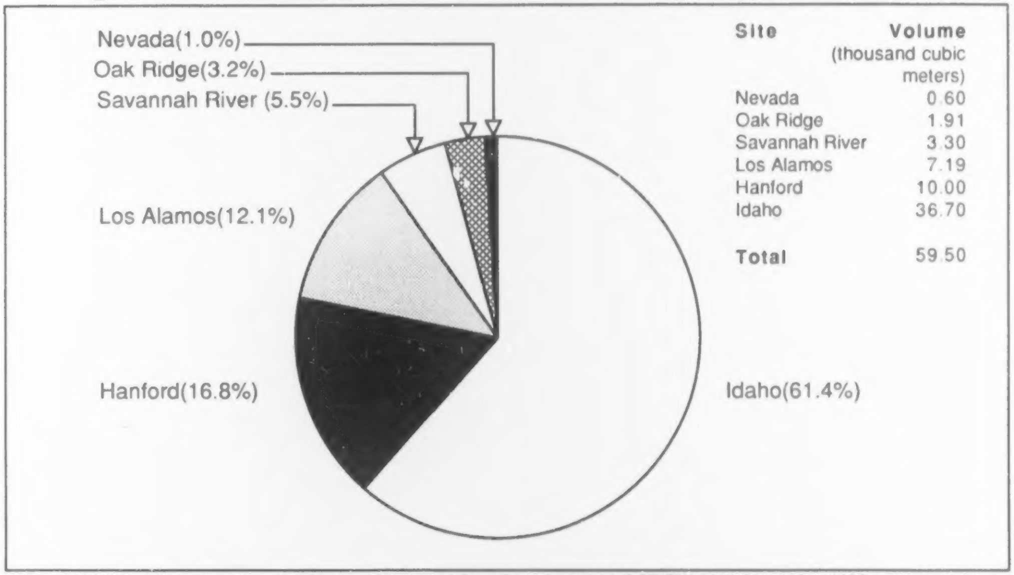
[8] One exception to this statement is TRU waste produced during reprocessing of commercial reactor fuel at West Valley, NY, between 1966 and 1972.

Figure 2-1—Total Volume of Retrievably Stored DOE Transuranic Waste Through 1988



Site	Volume (thousand cubic meters)
Nevada	0.60
Oak Ridge	1.91
Savannah River	3.30
Los Alamos	7.19
Hanford	10.00
Idaho	36.70
Total	59.50

SOURCE: U.S. Department of Energy, "Integrated Data Base for 1989," DOE/RW-0006, November 1989.

In 1984, the level defining the lower concentration limit for TRU waste was increased from 10 to 100 nanocuries per gram. Waste that contains transuranics below this level can be treated as LLW. The latter level was reportedly chosen "because it is similar to the level of the naturally occurring TRU in ore" (17). Another consideration may have been the cost savings for treatment and disposal. In addition, new assay techniques permitted determining TRU concentrations down to the 100 but not the 10 nanocuries per gram level. Some issues concerning the definition of TRU waste are discussed later.

Amount and Distribution

Some Integrated Data Base Estimates

The 1989 DOE Integrated Data Base provides the following information on TRU waste at DOE weapons sites at the end of 1988. TRU waste radioactivity, estimated at 3.94 million curies, is about 0.34 percent that of defense HLW and about 30 percent of defense LLW (76). On the other hand, its volume, 251,000 cubic meters, is 65 percent that of HLW and 10 percent of LLW (76).

TRU waste is more widely distributed geographically than high-level waste. Figure 2-1 shows the total volume of *retrievably stored*[9] TRU waste through 1988 (78). This waste is spread over six sites, ranging from the Idaho National Engineering Laboratory (INEL) with 61 percent of the total to the Nevada Test Site with 1 percent of the total. The estimated volume of *buried* TRU waste is more than three times the volume of retrievably stored TRU waste (80). Buried TRU waste is also located at six sites, five of which contain retrievably stored TRU waste. Hanford has the largest share of buried TRU waste by volume (57 percent) followed by INEL (30 percent). The IDB estimates that the radioactivity of buried TRU waste is less than 2 percent that of retrievably stored TRU waste (83). However, buried waste estimates are subject to great uncertainty.

Figure 2-2 shows both points of origin and storage sites of DOE TRU waste. Although five sites are

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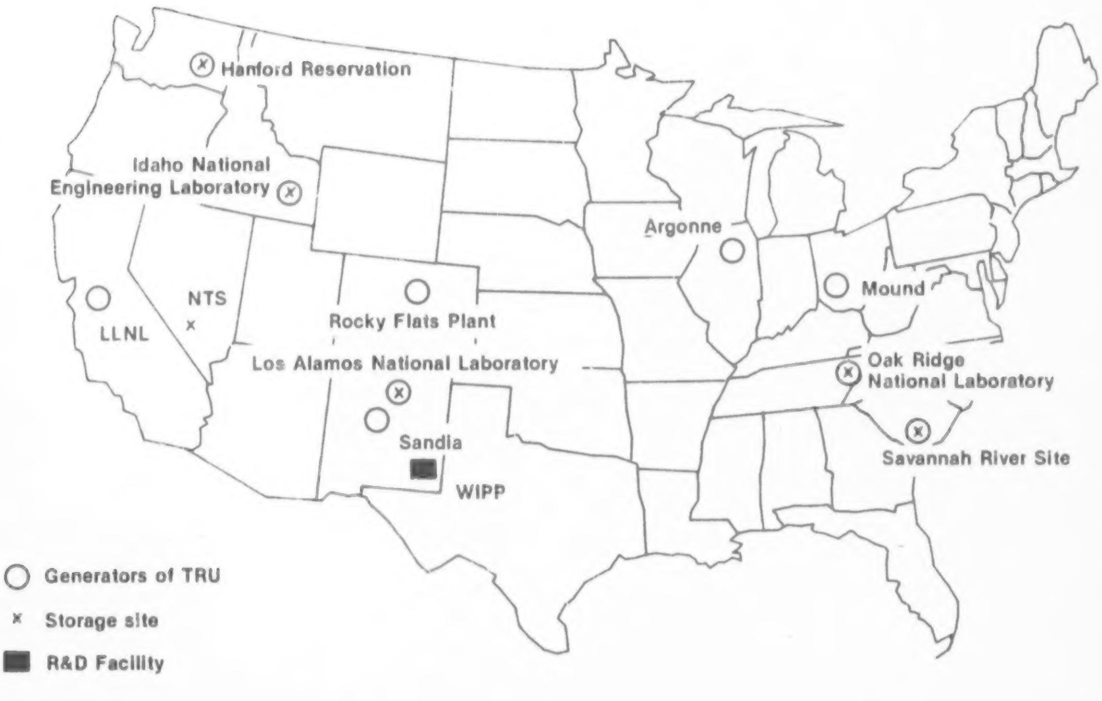
[9] TRU waste is divided in the IDB into retrievably stored waste and buried waste. Estimates of the amounts of retrievably stored waste are likely to be the more accurate because some buried waste locations may not be known or characterized. No TRU waste was buried after 1978 (78). Presumably, buried waste volumes are educated guesses, aided in part by some historical inquiry and records. Less uncertainty is associated with the amounts of retrievably stored waste. In the past, DOE designated all waste that contained transuranic materials as TRU waste, whether or not significant, separable amounts of LLW waste were also present. However, more recently, driven by limitations on storage of mixed waste at Rocky Flats, DOE has been increasing its use of nondestructive assay techniques to segregate TRU waste from LLW. Sampling efforts have led DOE to estimate that 38 percent of all stored waste originally categorized as TRU waste is in fact LLW, and TRU waste inventories have been lowered accordingly (80). Further changes can be expected.

Figure 2-2—Points of Origin and Storage Sites of DOE Transuranic Waste



SOURCE: U.S. Department of Energy, "Integrated Data Base for 1989," DOE/RW-0006, November 1989.

indicated as waste generators only, some interim storage of TRU waste is taking place at the Rocky Flats Plant as a result of a decision in September 1989 by the Governor of Idaho not to accept any more shipments of TRU waste from Rocky Flats. Other generator locations shown on figure 2-2 but not included in figure 2-1, also have TRU waste on-site.

Figure 2-3 shows the distribution among sites of contact-handled versus remote-handled TRU waste. According to table 3.5 of the 1989 IDB, 88 percent by volume (62 percent by radioactivity) of the "hotter," remotely handled stored waste is at Oak Ridge National Laboratory (ORNL) (81). From that table, remote-handled stored waste can be estimated at 1.6 percent of the total volume (3.6 percent of the radioactivity) of stored TRU waste (81). In contrast to contact-handled TRU waste, which emits predominantly alpha radiation, remote-handled TRU waste has significant amounts of the more penetrating non-alpha radiation (gamma, beta, or neutrons). More than half (56.5 percent) of the total 1988 alpha radioactivity of retrievably stored, contact-handled waste is at Savannah River, some 653,000 curies. The alpha radioactivity at INEL, 73,000 curies, constitutes about 60 percent of all buried TRU alpha radioactivity (82).

Figure 2-4 shows total system inventories, projections, and characteristics of all buried and stored TRU waste as of 1988, projected in 5-year increments through the year 2013.[10] Several items should be noted: buried waste in 1988 is indicated as having

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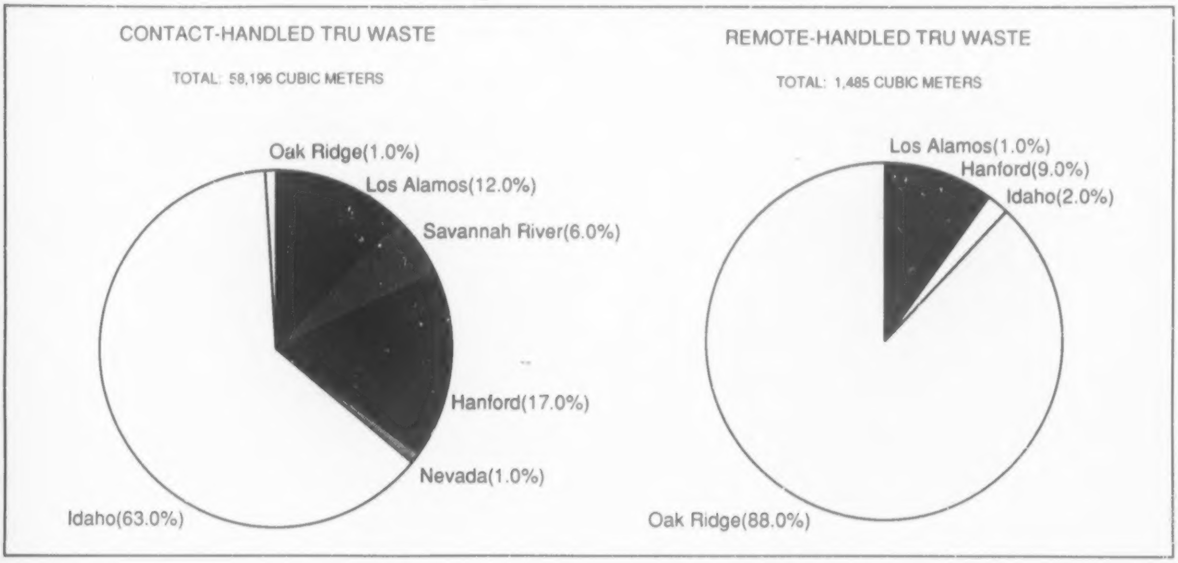
[10] The use of different estimating methods in the IDB leads to considerable difficulty in summarizing TRU waste inventory information. Values of radioactivity in figure 2-4 were calculated by using estimated isotopic compositions for TRU waste and a computer model. Volumes of stored waste are stated to be "certified TRU waste" and to exclude waste managed as LLW. On the other hand, values for figure 2-3 were derived from data provided by the field offices that include estimates of volume and alpha radioactivity for waste certified as TRU waste plus stored waste to be managed as LLW. Using figure 2-4 to compute the percentage of radioactivity associated with remote-handled waste gives results very different from figure 2-3.

Figure 2-3—Volume of Retrievably Stored Contact-Handled (CH) and Remote-Handled (RH) Transuranic Waste Accumulated Through 1988



SOURCE: U.S. Department of Energy, "Integrated Data Base for 1989," DOE/RW-0006, November 1989.

only 1.6 percent the radioactivity of total TRU waste,[11] although its volume is more than three times that of stored TRU waste; large annual increases in the radioactivity of stored, contact-handled waste are projected through the year 2013; there is a very large projected increase in the radioactivity of total stored waste to the year 2013, to more than 3.5 times the 1987 value. The last item is in marked contrast to the current projections of little or no change in total radioactivity of stored high-level waste over the same time period. (See ch. 1.)

Changes in Estimated Amounts

The 1989 IDB contains some major changes in TRU waste estimates (77). The value given there for the radioactivity of buried TRU is only 25 percent that given in the IDB for the previous year (74). This major reduction in radioactivity is due primarily to a drastic change in the reported radionuclide composition of Hanford buried waste from almost all plutonium-239 to almost all uranium.[12] The change may be indicative of uncertainties in the IDB.

A highly significant change took place in estimates of TRU retrievably stored waste between the 1987 and 1988 IDB. Some 38 percent of what had been classified as TRU waste was reclassified as LLW. There were also some substantial upward revisions of estimates of the radioactivity of contact-handled TRU waste at Hanford and Savannah River, as well as a drop in the radioactivity of remote-handled waste at ORNL. By contrast with the relatively minor changes from year to year in HLW inventories, the large changes in TRU inventories appear to reflect greater uncertainties in these estimates.[13] The uncertainties are probably greater for buried waste, although information on stored

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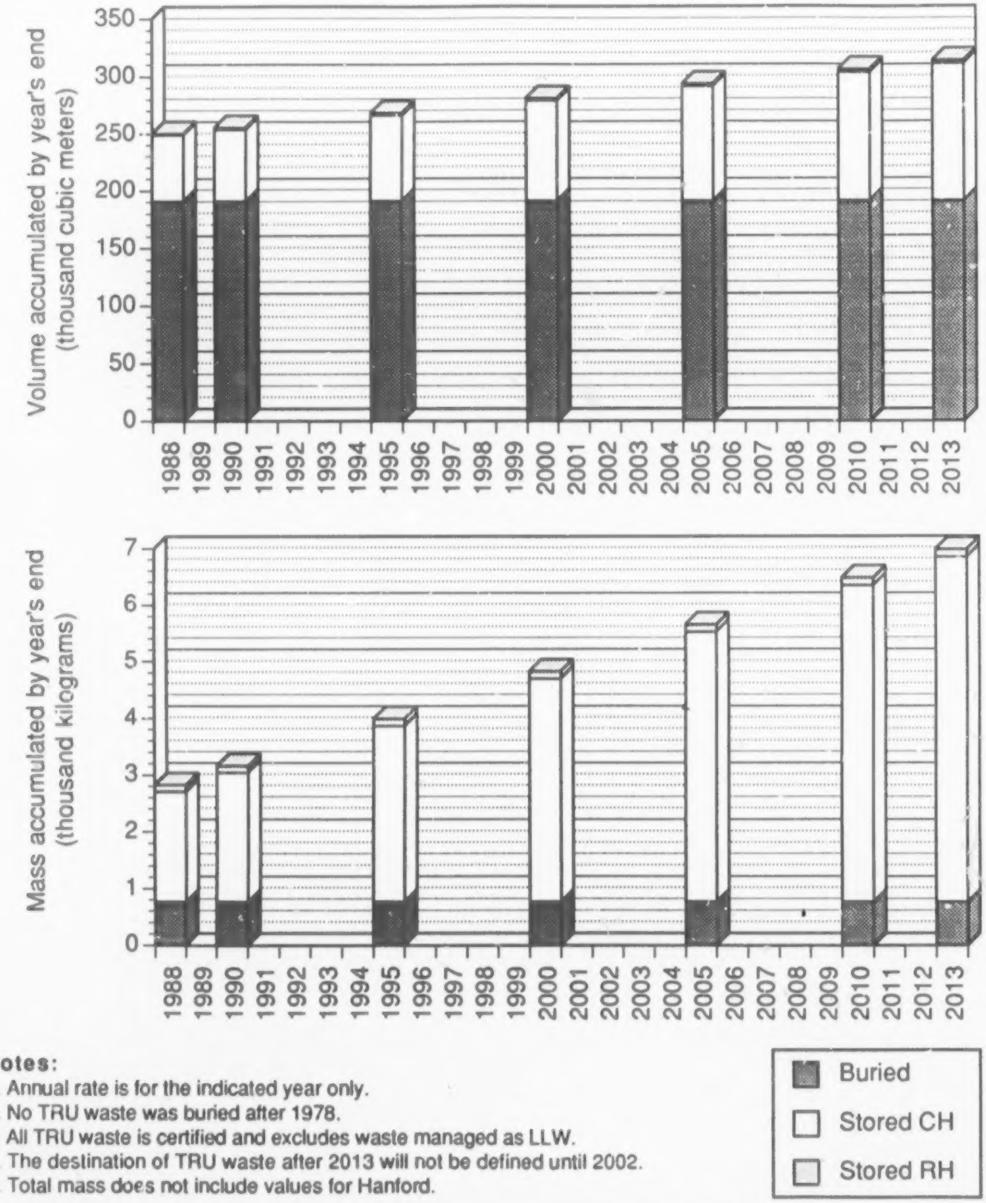
[11] It should be noted that radioactivity estimates of buried TRU waste are highly uncertain.

[12] Klein, J.A., Oak Ridge National Laboratory, personal communication, Apr. 16, 1990.

[13] This becomes particularly important in tracking the amount of waste scheduled to be shipped to the Waste Isolation Pilot Plant (WIPP). It has been pointed out that a tenfold reduction in the total radioactivity of remote-handled TRU waste destined for WIPP occurred from the final WIPP Environmental Impact Statement (EIS) to the supplementary EIS (23). Because this amount includes waste yet to be generated as well as stored waste, the reduction could be due to changes in the projected amount of waste to be generated, changes in the estimates of existing waste, or some combination of both. The IDB is of no help in sorting this out.

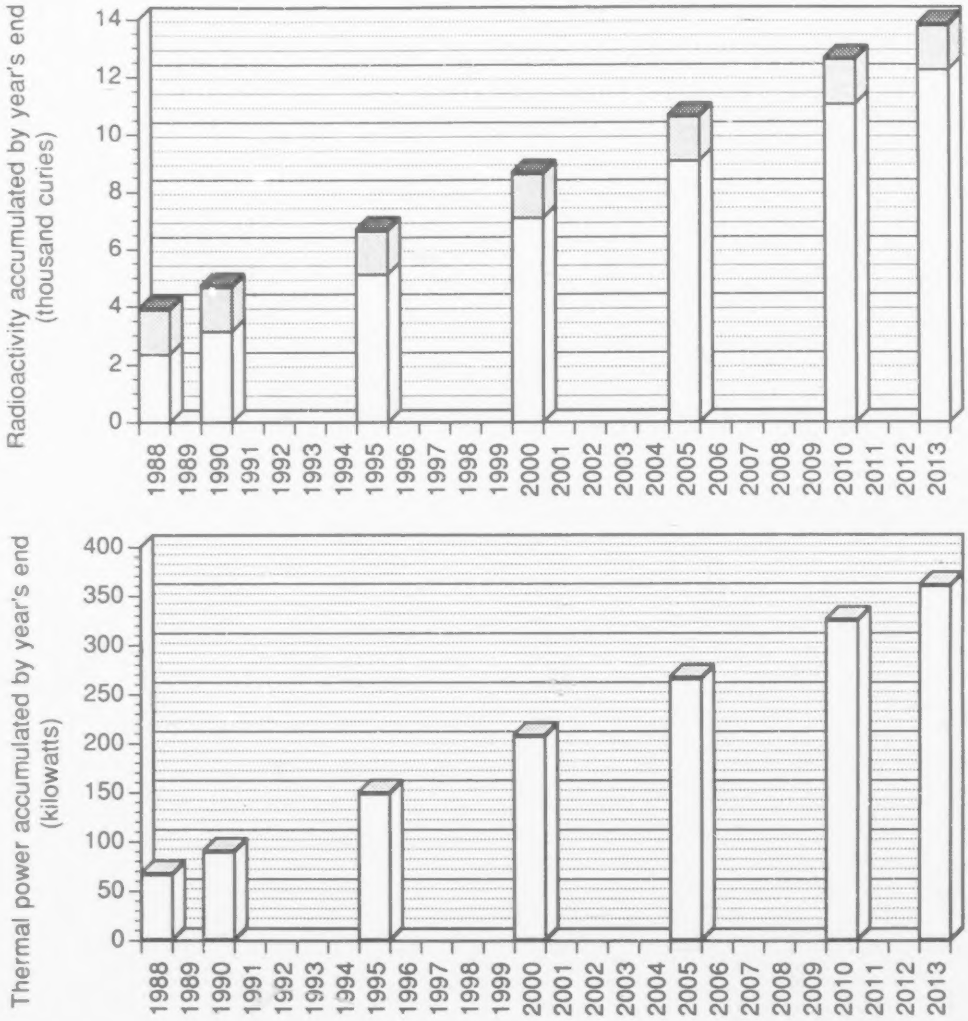
Figure 2-4—Total System Inventories, Projections, and Characteristics of All Buried and Stored DOE Transuranic Waste



Notes:

a. Annual rate is for the indicated year only.
b. No TRU waste was buried after 1978.
c. All TRU waste is certified and excludes waste managed as LLW.
d. The destination of TRU waste after 2013 will not be defined until 2002.
e. Total mass does not include values for Hanford.

Figure 2-4—Total System Inventories, Projections, and Characteristics of All Buried and Stored DOE Transuranic Waste—Continued



Notes:

a. Annual rate is for the indicated year only.
b. No TRU waste was buried after 1978.
c. All TRU waste is certified and excludes waste managed as LLW.
d. The destination of TRU waste after 2013 will not be defined until 2002.
e. Total radioactivity and thermal power do not include values for Hanford.

KEY: CH=contact-handled; RH=remote-handled.

SOURCE: Adapted from U.S. Department of Energy, "Integrated Data Base for 1989," DOE/RW-0006, November 1989.

Table 2-2—Inventories and Characteristics of Soil Contaminated With DOE Transuranic Waste Through 1988

Site	Volume (cubic meters)	Mass of TRU nuclides (kilograms)	TRU alpha radioactivity (curies)
Hanford Plant	31,960	190.2	16,706
Idaho National Engineering Laboratory	56,000-156,000	[a]	[a]
Los Alamos	1,140	[a]	[a]
Mound Plant	300-1,000	0.009-0.029	150-526
Oak Ridge National Laboratory	13,000-61,000[b]	[a]	[a]
Savannah River Site	38,000	[a]	[a]
Total	140,400-289,100	[a]	[a]

[a] Reported as unknown.

[b] If soil containing TRU waste can be isolated from 1,600,000 cubic meters of soil containing TRU and LLW waste. Total also includes 1,000 cubic meters of contaminated soil around tanks.

SOURCE: U.S. Department of Energy, "Integrated Data Base for 1989," DOE/RW-0006, November 1989.

waste is also difficult to interpret. The stored waste appears to be undergoing systematic assay, which will result in reclassifing some TRU waste as LLW. In the meantime, attempts to utilize data in the IDB should be viewed with caution; the data lend themselves to manipulation because some waste may not have been identified and documented; in the past, different facilities have used different data gathering procedures. Some improvements have taken place in the IDB; hopefully, more will be forthcoming.

Table 2-2 provides a partial estimate of inventories and characteristics of soil contaminated with DOE defense TRU waste through 1988. Only the radioactivity at Hanford and Mound are estimated, with the latter reporting a large range whereas Hanford provides a specific number estimate to five significant figures. A range of volumes is given for the Idaho National Engineering Laboratory (INEL) and the Oak Ridge National Laboratory (ORNL), indicating great uncertainty in the estimates; furthermore, at least for Oak Ridge, the volumes are predicated on being able to separate TRU waste from a much larger volume of soil containing both TRU and LLW. The values of volume and mass in table 2-2 are characterized as "very difficult to accurately determine" (77).

Waste Management: Present and Planned

Major changes in the management of TRU waste are underway at DOE facilities. Prior to 1970, TRU waste was disposed of by shallow land burial and not distinguished from LLW. By the end of this century, DOE plans to begin to dispose of TRU waste by placement of "certified" packages in a deep geologic repository. The transition from pre-1970 to 21st century practices involves a complicated set of technical and regulatory developments.

Beginning in 1970 (61), a policy was implemented that is characterized by monitored retrievable (interim) storage. For contact-handled TRU waste, the approach taken by DOE and its predecessor agencies was construction of large concrete or asphalt pads on which drums or boxes of waste could be stacked, protected with weatherproofing material, and, in some cases, periodically covered with earth. Sumps were provided for collecting any moisture present, and air sampling equipment measured humidity and radioactivity. Six of its operations offices are reported by DOE to manage such facilities: Albuquerque, NM; Richland, WA; Idaho; Nevada; Oak Ridge, TN; and Savannah River, GA. Also stored are relatively small quantities of remote-handled TRU waste under conditions that provide shielding from radiation. DOE asserts in the 1989 Five-Year Plan that no migration of radioactive or chemical contaminants has occurred (61). The retrievably stored TRU waste packages were designed to last for at least 20 years (55); some of these packages are now 20 years old.

It is DOE's current policy that all stored or yet-to-be-generated TRU waste, both contact- and remote-handled, will be disposed of in a geologic repository. According to the 1989 Five-Year Plan, "the Waste Isolation Pilot Plant (WIPP) near Carlsbad, New Mexico, will be the disposal facility for TRU waste. A Waste Acceptance Criteria Certification Committee, consisting of representatives from the Environmental Protection Agency (EPA), the State of New Mexico, and DOE negotiated and established stringent criteria on the form of waste acceptable at the Waste Isolation Pilot Plant"

(60).[14] Although some waste may be certified acceptable at the point of generation, other waste must be treated because it is known to be noncertifiable or because there is uncertainty about its contents (60). Plans call for a five-year test phase at WIPP, followed by a decision as to whether or not the disposal phase should proceed.

WIPP was not designed to serve as a repository for disposal of pre-1970 buried TRU waste, and DOE has no plan yet for the disposal of that waste, should it be removed from any existing sites. Some form of treatment of buried TRU waste in place (in situ) is a distinct possibility.

WIPP[15] was originally scheduled to begin accepting waste in 1988. As of July 1990, although construction of the facility was essentially complete, no TRU waste had been placed in WIPP on any basis, experimental or otherwise. In June 1990, Secretary of Energy James Watkins made a positive "readiness decision," asserting that DOE was ready to move ahead with a test phase that would involve placement of a small amount of the contact-handled TRU waste eventually planned for disposal. The experimental phase is expected to begin in 1991. If a positive decision is made to utilize WIPP as a disposal facility, such operations could probably not begin until 1995 or later. Many obstacles must be overcome before WIPP can fulfill its mission and the outcome remains uncertain. WIPP is discussed later in this section.

Because TRU waste is stored at a minimum of six Weapons Complex sites, a variety of facilities and equipment exist for its handling and interim storage. Some of these facilities were developed after the 1970 decision to retrievably store TRU waste but before the 1980 decision to proceed with WIPP. Several sites began certifying waste for WIPP in the mid 1980s. Existing facilities include the Stored Waste Examination Pilot Plant at INEL; the TRU Storage and Assay Facility at Hanford; the Size Reduction Facility, Treatment Development Facility, and three other facilities at Los Alamos; the TRU Waste Examination Assay Facility at Oak Ridge; and the Waste Certification Facility at Savannah River. The Rocky Flats Plant also certifies virtually all of its TRU waste at its own facility (56).

Figure 2-5 from the 1989 Five-Year Plan summarizes the six new facilities planned to begin operation during 1992-99 for processing, treating, and certifying TRU waste—both retrievable and newly generated—for shipment to WIPP. According to the 1989 Five-Year Plan, the Processing Experimental Pilot Plant (PREPP) in Idaho will be the first facility to process currently uncertifiable TRU waste;[16] it will shred, incinerate, grout, and produce 55-gallon drum packages. Also at INEL, the Retrieval Containment Building (RCB) will allow for year-round storage of drums in weathertight containment; the Transuranic Waste Treatment and Storage Facility will provide for examination, handling, shredding, compaction, and repackaging of container contents. The Transuranic Waste Facility at Savannah River will retrieve waste from storage and will vent, purge, shred, and repackage drums; reduce the size of and repackage bulky waste; and solidify liquid waste. The Waste Receiving and Processing Facility at Hanford will inspect packages and perform assaying, repackaging, size reduction, compaction, sorting, shredding, and waste immobilization in grout. If DOE decides it is necessary, incineration will be included between the shredding and grouting operations. The Waste Handling and Packaging Plant at Oak Ridge will process retrievably stored and newly generated TRU waste into a WIPP-acceptable waste form; it will also process remotely handled TRU waste (60).

A June 1987 DOE document estimates that TRU waste management costs for stored and newly generated waste will be $3 billion through the year 2013; this figure is subject to modification. Cost estimates of remedial action for buried TRU-contaminated waste and soil range from between $200 million and $2 billion if waste and soil are left in place, to between $6 billion and $10 billion if they are exhumed and disposed of in a repository (57).

Figure 2-2 shows the points of origin and storage sites for TRU waste. Note that there are more generators than storage locations. Of particular interest is the movement of TRU waste from Rocky Flats to INEL, a path that has been blocked by the Governor of Idaho since September 1, 1989, leading

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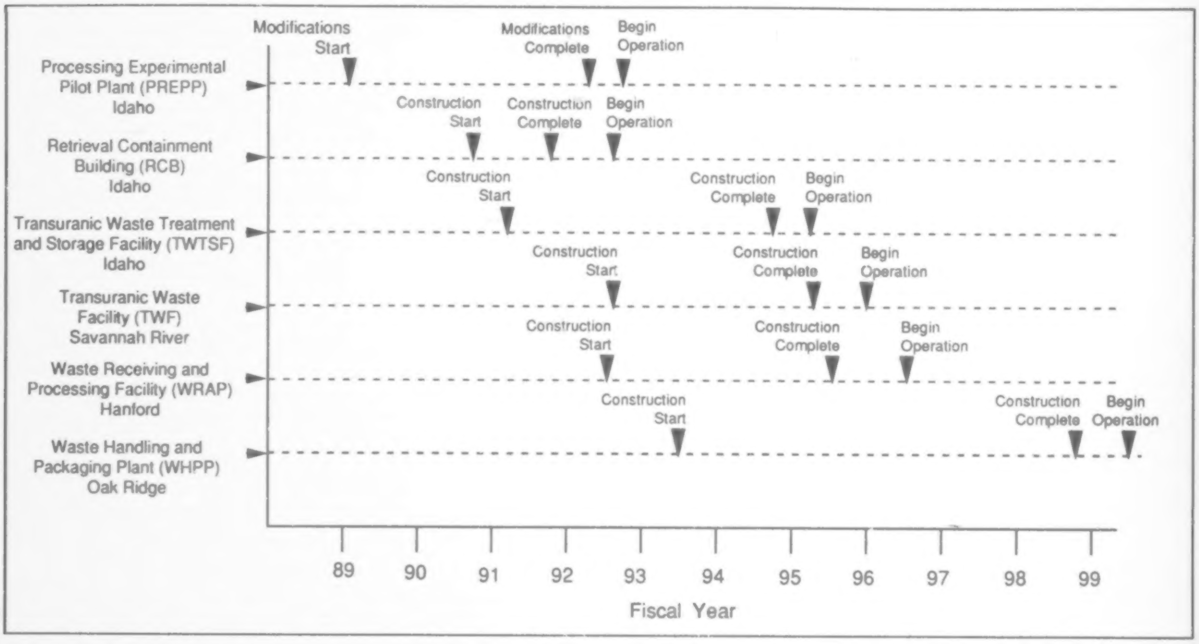
[14] Establishing the criteria appears to have been solely a DOE responsibility because both EPA and New Mexico's Environmental Evaluation Group have served on the committee in an advisory capacity only.

[15] The Waste Isolation Pilot Plant was authorized by the Department of Energy National Security and Military Applications of Nuclear Energy Act of 1980 (Pub. L. No. 96-164).

[16] Although PREPP is shown with a 1992 start date in the 1990 Five-Year Plan, its future, as of late 1990, is uncertain.

Figure 2-5—Planned Facilities To Process, Treat, and Certify Transuranic Waste for Shipment to the Waste Isolation Pilot Plant



SOURCE: U.S. Department of Energy, "Environmental Restoration and Waste Management: Five-Year Plan," DOE/S-0070, 1989.

to what has been called a storage crisis for Rocky Flats TRU mixed waste.

Current and Potential Problems

Buried Waste and Contaminated Soil

During the roughly 25 years of the nuclear era prior to 1970, waste contaminated with TRU elements was not distinguished from LLW and was disposed of in the same manner. Such disposal usually consisted of dumping contaminated clothing, metal, glass, other objects, and liquids into the soil or into solid trenches that were covered with soil. Information on how much, and where, such waste is located at DOE weapons sites is incomplete. The Integrated Data Base (77) indicates that the largest volume of buried TRU waste is located at Hanford, whereas the highest radioactivity of TRU waste is buried at INEL (see table 2-3). In addition, the IDB also gives some inventories and characteristics of soil contaminated with TRU waste, with INEL having the largest volume (see table 2-2); however, the degree of uncertainty is evident from the manner in which the volume is listed, ranging from 56,000 to 156,000 cubic meters. Furthermore, values of radioactivity for four of the six sites listed in table 2-2 are said to be unknown.

Information about buried TRU waste sites and TRU contaminated soil is far from complete. Information is scarce about the location of these sites, the extent and makeup of contamination, and the extent of migration of radioactive nuclides. A coordinated effort to explore the history of the sites, employing—among other techniques—interviews with retired workers, could aid in locating and characterizing buried TRU waste.

Throughout the DOE Nuclear Weapons Complex, TRU waste was buried prior to 1970 under conditions that led to the uncontrolled release and migration of radionuclides into the environment. Various DOE Environmental Survey reports indicate that buried TRU waste has caused environmental contamination in at least three facilities: the Savannah River Site, INEL, and Los Alamos National Laboratory. Data on the extent of contamination from buried TRU waste at these and other sites are sketchy, but the following examples provide some insight into possible risks.

1. *Idaho National Engineering Laboratory*: At INEL, TRU waste was received for nonretriev-

Table 2-3—Inventories and Characteristics of DOE Buried Transuranic Waste Through 1988

	Values reported by storage site as of Dec. 31, 1988		
Site	Volume (cubic meters)	Mass of TRU nuclides (kilograms)	TRU alpha radioactivity[a] (curies)[b]
Hanford[a]	109,000	346	29,200
Idaho National Engineering Laboratory	57,100	357	73,267
Lawrence Livermore	14,000	53.5	9,230
Oak Ridge National Laboratory	6,200	5.6	270[c]
Sandia	3	1	1
Savannah River Site	4,534	9.1	9,831
Total	190,837	771.2	121,799

[a] Includes soil mixed with buried waste.

[b] As reported by storage sites, it does not include beta and gamma radioactivity or radiation from decay products.

[c] Total of all radioactivity.

SOURCE: U.S. Department of Energy, "Integrated Data Base for 1989," DOE/RW-0006, November 1989.

able burial in shallow pits from 1954 to the 1960s at the Radioactive Waste Management Complex (RWMC), an area that expanded from 13 to 88 acres during this period. An environmental survey performed in 1987 included a review of monitoring records; interviews with EPA, DOE, and State personnel; and sampling and analysis of selected media. According to preliminary DOE survey results (66), plutonium-238 and 239 and americium-241 were detected at above-background levels in the RWMC, with the highest concentrations in surface soil at the perimeter drainage area where water drains from the top of the subsurface disposal area (SDA). Plutonium contamination was detected and americium contamination was estimated to have moved thousands of feet from the burial site. High concentrations of contaminants near the perimeter of the site were believed due to floods in 1962 and 1969, as well as to localized drainage of water from the surface. Lower concentrations away from the site perimeter were believed to result from wind transport. On completion of these studies, portions of the burial ground were covered with additional topsoil from noncontaminated areas and seeded for ground cover. Other improvements were also made, such as grading to improve drainage and to lower the potential spread of contamination.

According to the INEL survey, studies indicate the presence of plutonium-238 and 239 at the 110-foot interbed beneath the RWMC. The present contractor, EG&G, claims that the concentrations involved do not present a health concern for the near future, because the plutonium is strongly bound to soil particles in the sediment of the interbed layer. This contrasts with the relative ease of plutonium transport through fissured lava. Groundwater is located some 200 feet beneath the RWMC and is contaminated with volatile organic compounds. The survey expressed concern that plutonium could have migrated with these organics but to OTA's knowledge, no evidence of this has been reported.

2. *Los Alamos National Laboratory* (LANL): At LANL, the first solid waste disposal area, a 6-acre landfill known as MDA-B, opened in 1945 and closed in 1950. DOE has stated that radioactive waste in the landfill is likely to include plutonium, polonium, uranium, americium, curium, lanthanum, actinium, and mixed fission products. Waste was reportedly packaged in cardboard boxes or wrapped in paper; an inventory of waste volume and radioactivity is not available. Hazardous waste chemicals placed in MDA-B include organics, perchlorates, ethers, solvents, and corrosive gases.

It is uncertain whether the landfill is one large, continuous pit or a series of six pits. During its operation, waste was probably not covered daily and spontaneous fires also occurred. These past operational practices could have allowed contaminants to migrate beyond the present fenced portion of the landfill, which is located very close to the edge of a mesa top; therefore, the canyon wall on the downslope side of MDA-B may have received contaminated runoff. In addition, waste placed in MDA-B may be a continuing source of contamination to subsurface soil and the vadose zone (67).

Similar contamination may have occurred from the MDA-C inactive landfill, which operated from 1948 to 1974 for disposal of both radioactive and chemical waste. As of January 1973, approximately 50,000 curies of radioactive material was present, including uranium isotopes, plutonium-239, americium-241, tritium, fission products, and induced radioactivity; chemical waste included pyrophoric metals, hydrides, powders, and compressed gases. Waste pits and most of the waste shafts were unlined. Only in 1984 were surface stabilization measures completed at MDA-C, which may help to reduce the potential for downward migration of contaminants.

3. *Savannah River*: Here, the Radioactive Waste Burial Grounds are used for disposal of a variety of waste, including TRU waste. Until 1965, TRU waste was loaded into plastic bags and cardboard boxes that were buried in earthen trenches. Between 1965 and 1974, TRU waste was segregated into two categories: waste with a radioactivity level of 0.1 curie per package or higher was either buried in retrievable concrete containers or encapsulated in concrete; waste with radioactivity lower than 0.1 curie per package was buried unencapsulated in trenches. Since 1974, TRU waste with radioactivity higher than 10 nanocuries per gram has been stored on an interim basis in watertight containers that can be retrieved intact up to 20 years from the time of storage. DOE monitoring wells have detected contaminated groundwater within and at the edges of the burial ground. The gross alpha levels measured are several times those permitted by drinking water standards. According to the DOE 1987 Environmental Survey for the site, monitoring and characterization are quite incomplete (68,93).

In 1987, DOE set forth, in general terms, a plan for buried TRU-contaminated waste and soil as follows: "to characterize the disposal units; assess the potential impacts from the waste on workers, the surrounding population, and the environment; evaluate the need for remedial actions alternatives; and implement and verify the remedial actions as appropriate" (57). However, DOE has just begun this process. Characterization of, and strategies for dealing with, buried TRU waste and contaminated soil are in the very early stages.

A panel of the National Academy of Sciences is monitoring the DOE environmental restoration program dealing with buried TRU waste at INEL. At a November 1989 meeting of the panel, some of the problems encountered were summarized by DOE as follows: "site characterization needs to be much more developed;" "waste migration needs better definition;" "a decision process [for what to do with the buried waste] with well-developed evaluation criteria needs to be implemented;" and "where the waste would be placed, once retrieved, is open to question."[17] With regard to the last point, it was also stated that DOE may not want to set a precedent by removing buried waste from Idaho.

A number of specific technical studies conducted for DOE were reported at the National Academy of Sciences meeting. One of these highlights a problem associated with buried waste, namely, the development of volatile organic compound plumes beneath the surface that might serve to accelerate the movement of radionuclides beneath the soil to groundwater. Efforts are underway to characterize the carbon tetrachloride plume in the vadose zone under the RWMC area at Idaho and to demonstrate a technology known as vapor vacuum extraction for removal of subsurface organic vapors.[18]

Waste Storage

Implementation of the 1970 decision to store TRU-contaminated waste so it would be retrievable for future disposal in a geologic repository has resulted in waste being stored at several DOE sites, usually in 55-gallon steel drums placed on concrete or asphalt pads. The integrity of the drums is of concern for two reasons: drum storage was meant to be an interim measure, and some drums have already held TRU waste for 20 years, the nominal design lifetime for these packages (55); and the WIPP repository is not expected to accept TRU waste for disposal until 1995 at the earliest, and possibly much later. Furthermore, after WIPP does open, it will take 20 to 30 years to fill the repository and a significant portion of DOE's TRU waste will still have to be stored for long periods of time pending shipment to WIPP.

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[17] Statements made by a U.S. Department of Energy representative during summation at National Academy of Sciences Panel to Review the DOE Assessment of Pre-1970 Buried Waste at the Idaho National Engineering Laboratory, Nov. 14, 1989.

[18] R.R. Piscitella, EG&G-Idaho, "Vapor Vacuum Extraction Demonstration Update," presentation with view graphs to National Academy of Sciences Panel to Review the DOE Assessment of Pre-1970 Buried Waste at the Idaho National Engineering Laboratory, Nov.13, 1989.

The Pad A Initial Retrieval Project at INEL was defined as part of a Resource Conservation and Recovery Act (RCRA) Facility Investigation Work Plan to determine, among other things, waste container integrity for drums of TRU waste received from Rocky Flats and stored at INEL in 1970-77, as well as associated radiological or hazardous contamination of the soil. In 1989, eight drums were reportedly retrieved from Pad A, of which six had rust holes up to 4 inches long; an EG&G project engineer is quoted as saying that even where the drums have corroded, internal polyethylene bags have contained the waste, mostly contaminated clothes, tools, and rags (12).

Along with the obvious technical concerns about container integrity, there are also regulatory problems. Much of DOE's stored TRU waste is mixed waste; that is, it has both radioactive and hazardous components. The duration of TRU waste storage at a particular DOE site is limited by EPA land disposal restrictions for mixed waste.

State governments are a major factor in regulating stored TRU waste. A situation that received a great deal of attention during 1989-1990 began on September 1, 1989, when the Governor of Idaho refused to permit further shipment of TRU waste from Rocky Flats to INEL (42).[19] The State of Colorado had established a limit to the amount of mixed TRU waste that could be stored at Rocky Flats. At first, DOE was quite concerned that the limit would be exceeded rapidly, forcing shutdown of Rocky Flats plutonium fabrication operations. However, the situation eased somewhat as a result of several factors: Rocky Flats has been shut down since late 1989 for various safety reviews and is thus generating less waste; efforts are moving ahead to assay or reassay stored TRU waste; both waste minimization and efforts to separate the hazardous and radioactive components of TRU mixed waste have reduced storage space requirements.[20] In April 1990, the situation took another dramatic turn when a Federal District judge in Denver ruled that thousands of drums of plutonium-containing material that DOE had considered "residue" (i.e., material from which plutonium would be recovered for future use) was in fact mixed waste subject to the State of Colorado imposed storage limit under RCRA (88). If this ruling were to be implemented, the Colorado storage limit for mixed TRU waste would have been exceeded. However, to date, the State of Colorado has not pursued implementation of this ruling and, instead, has been negotiating an agreement with DOE to resolve this matter.

DOE is pursuing several alternatives, mostly in response to the Rocky Flats situation for storage of mixed TRU waste. These include persuading the Governors of several States with weapons sites to accept some portion of the Rocky Flats waste; storing the waste at Department of Defense facilities; and storing the waste at a privately owned facility.[21] In February 1990, DOE announced that it was seeking proposals of plans for a privately owned and licensed facility for interim storage of TRU waste, including transportation from DOE generator sites and subsequent shipment to WIPP for disposal (91);[22] the waste would remain the property of the Federal Government.

Plutonium Handling and Contamination at Rocky Flats

The Rocky Flats Plant is DOE's facility for fabricating, assembling, and quality testing components to be placed in the triggers of thermonuclear weapons. As such, it carries out various plutonium, uranium, and beryllium production activities, as well as recovery by chemical processing of plutonium and americium from retired weapons and fabrication process residues (21). Its plutonium mission makes Rocky Flats a major generator of TRU waste.

Problems reported to have occurred at Rocky Flats since it began operating in 1952 include contamination, injury, and death of workers, attributed to accidents, spills, and fires (1). Retired Rocky Flats workers are suing for compensation, alleging that their cancers were due to radiation exposure. A 1957 fire resulted in release of an unknown amount of plutonium to the air; soil was also contaminated. In January 1990, eight current Rocky Flats workers and four retired workers had reportedly tested positive for berylliosis, an incurable disease that results from exposure to beryllium dust and is fatal to about 30 percent of those who contract it (9). Also in January 1990, two labor unions and Rocky Flats area residents filed two class-action lawsuits against Rockwell International Corp. and Dow Chemical Co., the two primary operating contractors at Rocky Flats prior to EG&G, alleging that careless and negligent treatment of hazardous waste had threatened their health and hurt them financially (10). In 1988, the State of Colorado cited Rocky Flats for nine violations of hazardous waste disposal laws.

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[19] GAO has concluded in a June 1, 1989, letter opinion to Representative Synar that there was no legal authority for the Governor's action. However, DOE has not pursued legal action to reverse it.

[20] U.S. Department of Energy congressional briefing on WIPP Decision Plan and Alternative Storage for Rocky Flats Plant Transuranic Waste, Feb. 22, 1990.

[21] Ibid.

[22] Ibid., viewgraphs.

There has been persistent concern about plutonium releases to the air, as well as plutonium contamination of soil and groundwater. These concerns have received increased attention because 1.4 million people live within 50 miles downwind of the plant.

A 1989 report by Scientech, Inc., indicated the presence of plutonium in ventilation pipes downstream from certain filters that should have prevented it from getting there. The Scientech team concluded that a criticality[23] incident had not taken place but indicated that such an occurrence was not impossible under certain circumstances; the report was critical of Rockwell management practices (41). More recently, EG&G revealed that ventilation piping and ducts contain 28 kilograms of plutonium, more than twice that estimated by the Scientech team and enough to make six or seven nuclear weapons (38).

Figure 2-6—DOE Rocky Flats Tiger Team Report

Observations

- No situations that pose an imminent threat to public health or the environment were observed.
- Implementation of the environmental programs lacks coordination and is hindered by poor communication. The lines of authority and responsibility are fragmented and not clearly defined. A strategy that integrates the existing management and information systems needs to be developed and implemented.
- Environmental monitoring programs require improvements to more accurately characterize and monitor plant-related emissions, discharges, and ambient conditions.
- Effective implementation of the site remediation program has been adversely impacted by poor communications, coordination, planning, and scheduling.
- The quality and reliability of sample collection, laboratory analyses, and other information generated in support of the environmental monitoring and restoration programs are not adequate to achieve program goals.
- Management and maintenance of the sewage treatment plant has low priority, resulting in inefficient operation, which could create problems in meeting future permit requirements.
- The 1987 Waste Stream Characterization Study, which is used to support waste management activities (e.g., permits and waste classification), does not reflect current waste processes at the plant. The study has never been fully reviewed. Consequently, internal inconsistencies exist. The scope of the study was not broad enough to serve as an effective waste management tool.
- A comprehensive strategy needs to be developed and implemented for performing activities required by the National Environmental Policy Act.

SOURCE: Summarized from U.S. Department of Energy, "Assessment of Environmental Conditions at the Rocky Flats Plant," DOE/EH-107, August 1989.

The DOE "Tiger Team"[24] report on Rocky Flats was released in August 1989 (54). Figure 2-6 is a summary of the principal observations listed in the executive summary of the report. The seriousness of the Rocky Flats situation is evident from the information presented above as well as the following: a June 1989 raid on the plant by the Federal Bureau of Investigation to investigate various violations, including the alleged running of an incinerator to burn hazardous waste against orders (7); withdrawal of Rockwell International as the principal operating contractor for the plant, with EG&G assuming responsibility; extended curtailment and shutdown of Rocky Flats operations, beginning in November 1989, followed by a series of safety reviews and evaluations (3); and the fact that Rocky Flats was considered by newspaper editors and broadcast directors to be the most important news story in Colorado for 1989 (6).

Waste Assay, Treatment, and Certification

DOE is faced with the task of assaying its stored waste to determine what portion may properly be classified as TRU waste. Previously, DOE had assumed that if there was any uncertainty about the nature of stored waste, it would be handled as TRU waste. More recently, because of concerns about finding suitable interim storage for TRU waste, coupled with advances in assay technology, DOE has been assaying previously stored TRU waste to determine if some portion of that waste can be reclassified, treated if necessary, and disposed of less expensively as LLW. An additional factor driving reclassification was the redefinition of the lower radioactivity limit for TRU waste from 10 to 100 nanocuries per gram in 1982. Based on sampling procedures and work to date, DOE estimates that 38 percent of its current inventory of retrievably stored TRU waste will be reclassifiable as LLW (79).

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[23] A criticality incident involves the unintentional buildup of fissile material such as plutonium-239 in an amount and geometry that would form a critical mass, in a piece of equipment not designed to contain neutron chain reactions. Consequences could include a major uncontrolled release of radioactivity. "A criticality accident at the Rocky Flats Plant could produce a potentially lethal dose of neutron and gamma radiation to workers at close range, could generate heat and fission products, and, in extreme but low probability circumstances, could result in the release of radioactivity to the environment" (41).

[24] During 1989 and 1990, DOE has conducted investigations of health, safety and environmental problems at each site utilizing an ad-hoc group specially selected by DOE headquarters. These groups are known as Tiger Teams.

In November 1989 DOE reached agreement with the State of Colorado to assess the substantial quantities of plutonium "residues" from incinerator operations at Rocky Flats to determine whether they have been properly classified or whether some portion should be considered TRU waste (37). In April 1990, a Federal district judge ruled that the materials in question did in fact constitute waste; DOE acknowledged that plutonium had been recovered from less than 10 percent of these residues during the past 5 years (88).

The certification of TRU waste involves two major steps. First, the waste must correspond to the definition of TRU waste, which currently excludes TRU-contaminated materials with alpha radioactivity lower than 100 nanocuries per gram. Second, according to current DOE plans, the waste package must meet Waste Acceptance Criteria for disposal in WIPP. Criteria for contact-handled TRU waste and remote-handled TRU waste were established in 1980 and are listed in the 1990 final supplement to the Environmental Impact Statement (EIS) for WIPP (69). Some of the existing stored TRU waste drums are or will be certifiable for shipment to WIPP as is. Others will have to be treated at one of the facilities planned to be developed by DOE.

The Waste Acceptance Criteria now in effect would allow a variety of waste contents and forms within the package to be placed in the WIPP repository. In general, TRU contaminants would not be immobilized in either the contact- or the remote-handled packages, and thus would be respirable and soluble if released. This is in marked contrast to the more uniform vitrified packages of high-level waste with immobilized radionuclides planned for emplacement in the high-level waste repository. Some of the remote-handled TRU waste packages for WIPP can have external dose rates as high as 1,000 rem per hour, exceeding that of some HLW vitrified glass logs. Even though only a small portion of the TRU waste is classified as remote-handled, it may be prudent to investigate the integrity of this waste package in more depth.

In preparation for WIPP operations, DOE is examining engineering alternatives for the WIPP waste package, driven in part by concern about gas generation after it is in the repository. It may be both necessary and desirable to modify the WIPP waste package to reduce or eliminate gas generation. Two possible classes of alternatives are: to shred, compact, and perhaps grout the waste; and to incinerate, calcine, or vitrify it.[25] The latter alternative would represent a major departure from current plans. Vitrification could eliminate gas generation in the repository and result in a more stable waste form. Disadvantages of vitrification are that it would require a major overhaul of current plans and treatment facilities at considerable expense and could possibly increase occupational exposure. A thorough analysis of these alternatives would be required before an informed choice could be made.

Transportation of Waste

Figure 2-7 shows the proposed transportation routes to WIPP. TRU waste is currently located at the DOE sites identified in the figure and must be transported over relatively long distances. Transportation of waste packages to WIPP represents the area of greatest public concern, as measured by the number of comments received about this topic in connection with the WIPP Supplemental Environmental Impact Statement (SEIS) (70).

The transportation option chosen by DOE is a fleet of trucks carrying the waste in specially designed "TRUPACT II" containers (see figure 2-8). The container design has been certified by the Nuclear Regulatory Commission (NRC) as suitable for shipping contact-handled TRU waste drums to WIPP.[26] A number of concerns have been expressed about the shipping plans including preparation for emergency response to traffic accidents, qualifications of the trucking contractors, specific routes used by the trucks, validity of accident analyses and structural integrity of the container (70). In addition to addressing these concerns in the SEIS, DOE has attempted to enhance safe transport by: developing a program to train State, local, and Indian tribal police and emergency personnel in proper proce-

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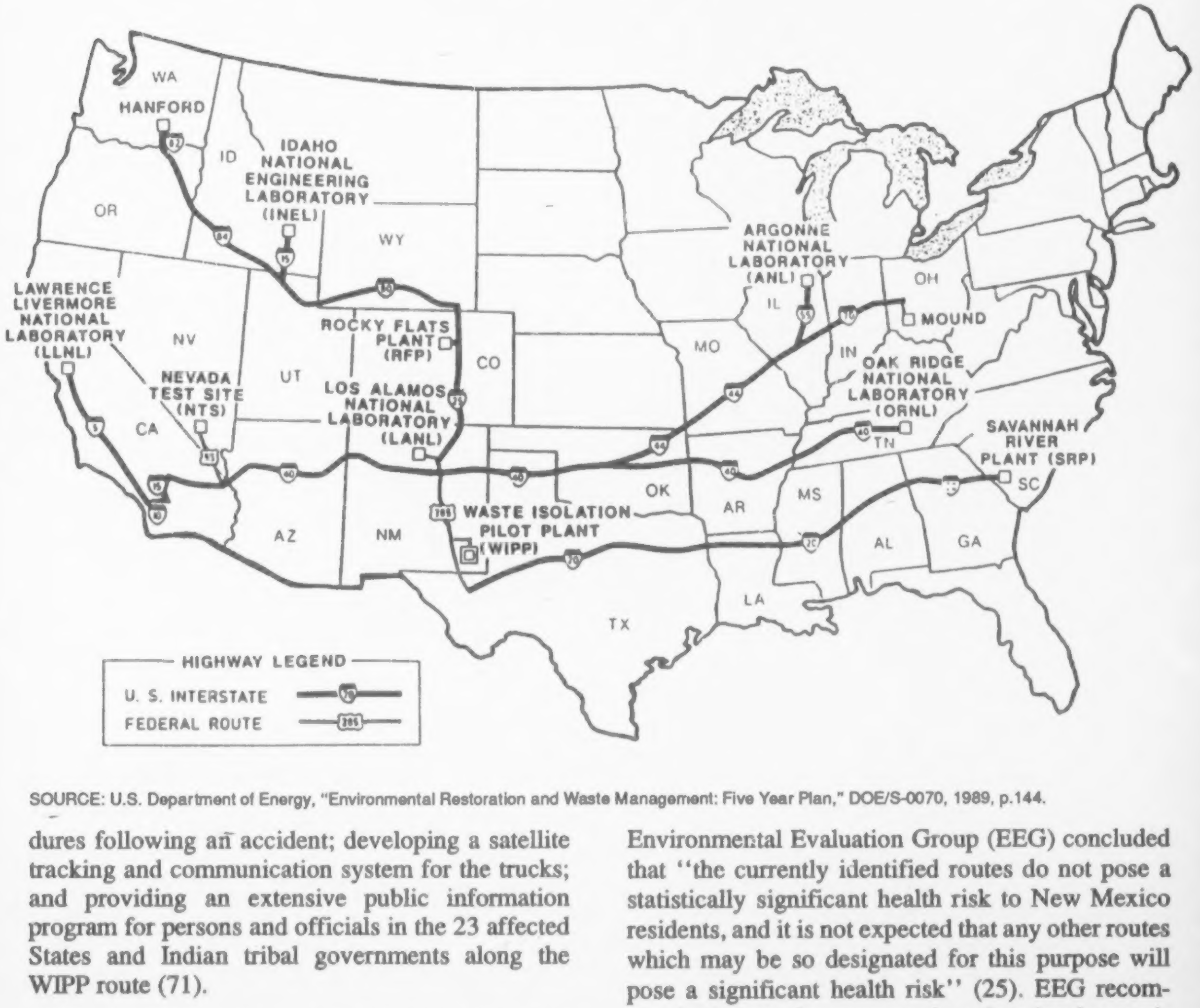
[25] Neill, R., Environmental Evaluation Group, personal communication, Mar. 26, 1990.

[26] For about a decade, DOE pursued a rectangular container design that was abandoned after failure to meet DOE's own standards.

Figure 2-7—Proposed Shipping Routes to the Waste Isolation Pilot Plant


WA
HANFORD
OR
ID
IDAHO NATIONAL ENGINEERING LABORATORY (INEL)
WY
LAWRENCE LIVERMORE NATIONAL LABORATORY (LLNL)
NV
NEVADA TEST SITE (NTS)
UT
CA
ROCKY FLATS PLANT (RFP)
CO
LOS ALAMOS NATIONAL LABORATORY (LANL)
AZ
NM
WASTE ISOLATION PILOT PLANT (WIPP)
TX
OK
MO
ARGONNE NATIONAL LABORATORY (ANL)
IL
IN
OH
MOUND
OAK RIDGE NATIONAL LABORATORY (ORNL)
TN
AR
MS
AL
GA
LA
SAVANNAH RIVER PLANT (SRP)
SC
HIGHWAY LEGEND
U. S. INTERSTATE
FEDERAL ROUTE
285

SOURCE: U.S. Department of Energy, "Environmental Restoration and Waste Management: Five Year Plan," DOE/S-0070, 1989, p.144.

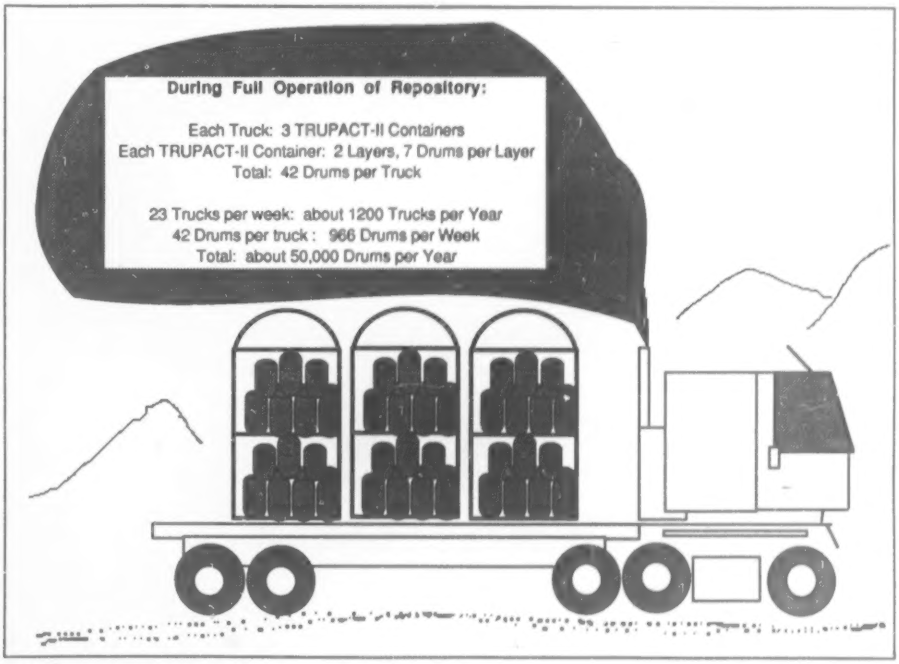
dures following an accident; developing a satellite tracking and communication system for the trucks; and providing an extensive public information program for persons and officials in the 23 affected States and Indian tribal governments along the WIPP route (71).

Despite DOE statements that the containers and trucks are safe, opposition to the transportation of TRU waste to WIPP is likely to continue. Among the concerns expressed at April 1990 hearings of the New Mexico State Environmental Improvement Board was a distrust of statements that there is little, if any, risk to public health and safety from the radioactive waste, either during transport or in WIPP itself (2,11). Transportation will bring the waste close to many people, and expressions of opposition have ranged from signs in Santa Fe reading "Another Business Against WIPP" to threats of civil disobedience.

In a March 1990 analysis of the risk of transporting contact-handled TRU waste to WIPP, the Environmental Evaluation Group (EEG) concluded that "the currently identified routes do not pose a statistically significant health risk to New Mexico residents, and it is not expected that any other routes which may be so designated for this purpose will pose a significant health risk" (25). EEG recommends that truck crew members be closely monitored to ensure exposures less than 2 millirems per hour, that selection of truck stopping places be carefully studied to minimize unnecessary exposure, and that bypasses around communities be used when possible (25).

To minimize the possibility of confrontation and avoid taking waste through urban areas, the State of New Mexico has sought funds to build a bypass around Santa Fe and other communities. At an April 1990 Senate Energy Committee hearing on WIPP, Secretary of Energy James D. Watkins and Senator Peter Domenici of New Mexico disagreed on whether the DOE was reneging on a commitment to

Figure 2-8—Bringing Trucks of TRU Waste Drums to the WIPP


During Full Operation of Repository:
Each Truck: 3 TRUPACT-II Containers
Each TRUPACT-II Container: 2 Layers, 7 Drums per Layer
Total: 42 Drums per Truck
23 Trucks per week: about 1200 Trucks per Year
42 Drums per truck : 966 Drums per Week
Total: about 50,000 Drums per Year

SOURCE: Office of Technology Assessment, 1991.

provide $250 million for New Mexico road construction.[27] New Mexico officials believe they had such a commitment of funds from DOE, whereas Secretary Watkins asserts that the commitment was to help obtain funds and not to provide them. States other than New Mexico through which the waste will pass are interested in the outcome of this controversy because they have road-building needs and desires of their own.

Finally, the question arises, what should be done if waste packages arrived at WIPP that were either damaged or uncertifiable for placement in the repository? WIPP appears to have very limited capability for handling damaged packages, as well as limited storage capacity. Also, there is no approved, above-ground storage facility at WIPP for mixed TRU waste.

The Waste Isolation Pilot Plant

The Waste Isolation Pilot Plant near Carlsbad, NM, is a key element in DOE's management strategy to dispose of retrievably stored and yet-to-be-generated TRU waste in a deep geologic repository, specifically, rooms mined in bedded salt 2,150 feet below the surface (see figure 2-9). The DOE 1989 Five-Year Plan calls for a 5-year demonstration or test phase to prove the WIPP concept will be undertaken. At the end of this demonstration phase, a decision will be made as to WIPP's acceptability as a permanent, operational, disposal facility for TRU waste. According to the Five-Year Plan, the 5-year test phase has two main objectives: to demonstrate that there is reasonable assurance of compliance of the WIPP disposal system with long-term EPA disposal standards, and to demonstrate the ability of DOE's TRU waste management system to safely and effectively certify, package, transport, and emplace waste at WIPP. After the test phase, the plan indicates that DOE will evaluate whether WIPP should proceed to the disposal stage (62).

Construction of the WIPP facility is essentially complete and WIPP was originally scheduled to open in 1988. It now appears that the first test phase could begin sometime in 1991 but opening date predictions are very difficult to make. Although

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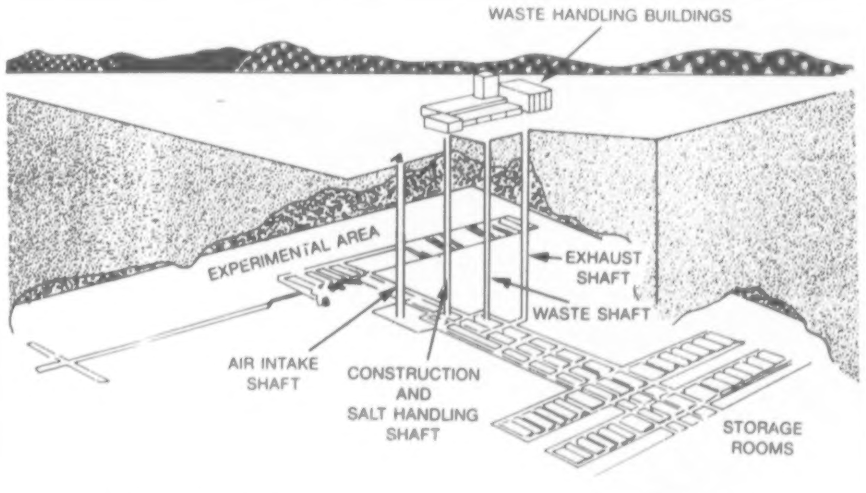
[27] From Senate Energy Committee hearing on WIPP, Apr. 3, 1990. See also *Weapons Complex Monitor*, "EPA Proposes to OK DOE WIPP Test Phase No-Migration Petition," Apr. 18, 1990, pp. 2-3.

Figure 2-9—The Waste Isolation Pilot Plant: Its Capacity, Estimated Operational Cost, and Estimated Lifetime



Total waste capacity:	6 million cubic feet
Current accumulated waste volume:	2.12 million cubic feet
Construction cost to date:	$700 million
Estimated cost for 25-year operation:	$2.5 billion
Estimated total time to fill the WIPP repository:	20 - 30 years

SOURCE: Office of Technology Assessment, U.S. Department of Energy.

considerable progress has been made in overcoming a sizable number of technical, regulatory, safety, and procedural obstacles, further obstacles and questions concerning the opening of WIPP remain to be addressed.

WIPP's importance extends beyond its role as a repository for TRU defense waste. To DOE Secretary Watkins, it represents an opportunity to make up for past mistakes and prove the competence of U.S. science and technology.[28] For others, it represents moving forward with the long-term disposal of radioactive (TRU) waste in an existing facility, whereas a high-level waste repository seems a more distant possibility. Some undoubtedly see the successful outcome of WIPP, not withstanding its defense mission, as a giant step forward for civilian nuclear power by demonstrating that radioactive waste can be disposed of somewhere and need not accumulate at reactor sites. Thus, a variety of pressures may make it difficult for DOE to determine fairly and objectively at the end of a test phase whether or not TRU waste can be deposited safely in WIPP. DOE's thrust is summarized in the following statement in the 1989 Five-Year Plan: "A positive determination by DOE and continuing shipments to WIPP . . . would mean fulfillment of a major DOE objective" (62).

A variety of mechanisms have been put in place that provide useful technical advice and a measure of oversight for WIPP. They include a DOE Blue Ribbon Panel, a National Academy of Sciences panel, a subcommittee of the DOE Advisory Committee on Nuclear Facility Safeguards, and the EEG. Of these, EEG is the only organization with a substantial full-time technical staff; it has been a continuing source of valuable technical advice and oversight for WIPP since its inception. Although EEG's funds come from DOE, it is associated with the State of New Mexico.[29] Other oversight groups have also provided important technical advice but because they are either volunteer panels with minimal staff that only meet occasionally or because their scope and duration of oversight is limited, their ability to make in-depth evaluations is limited.

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[28] Secretary of Energy James D. Watkins, testimony at hearing on WIPP before Senate Energy Committee, Apr. 3, 1990.

Problems With WIPP—Some of the technical problems confronting WIPP were summarized at the 1989 Waste Management Conference. At that time, according to EEG, DOE had not published a single report to document WIPP's progress toward compliance with EPA Standards for the Management and Disposal of Spent Nuclear Fuel, High Level and Transuranic Radioactive Wastes (40 CFR Part 191). Among the technical problems were brine inflow and associated scenarios, the need to designate backfill materials, and the need to carry out a WIPP performance assessment, including experiments as opposed to pure modeling. Operational readiness issues were also unresolved. In addition, waste handling dose criteria were said to be less stringent than for commercial operations because they were essentially DOE self-regulated rather than NRC-regulated.[30]

EEG has monitored a variety of WIPP activities. For example, in 1989, in observations pertaining to the WIPP Phase II Preoperational Appraisal, EEG found significant programmatic deficiencies in the WIPP operational health physics program.[31] Among the issues that needed to be addressed were technical staffing, control of potential contamination events, training of health physics technicians, improved radiological calibration and maintenance, use of controlled areas for nonradiological functions, internal audits, accreditation of the external dosimetry program, establishment of an internal dosimetry program, establishment of a health physics respiratory protection program, and resolution of effluent monitoring and air monitoring issues. Many of these issues were reiterated a year later.[32] While DOE continues to make progress addressing these issues, it appears that EEG oversight provides a valuable mechanism for checking on such progress.

Brine and Gas Generation—The choice of WIPP as a deep geologic repository for TRU waste was predicated upon making use of a salt bed as the medium for isolating the waste from the environment. The salt would plastically deform and close in on the waste, keeping it isolated from the environment for a sufficiently long period to conform with EPA disposal requirements. Theoretically, one of the virtues of salt was its undisturbed nature; that is, it was initially thought to be dry. An earlier choice of a salt mine in Lyons, KS, as a repository for high-level waste was abandoned after discovery that the area had been extensively mined and that a significant number of boreholes penetrated the supposedly isolated repository (33). At WIPP, although there was no prior intrusion, some water and brine were evident in the repository. The water or brine was not in great evidence during an OTA site visit at the repository in March 1990 because of evaporation, due in part to the ventilation system; however, the brine could be a factor in certain scenarios following closure of the facility.

More recently, the concern about brine has been replaced by a concern about gas generation in TRU waste packages. Given current WIPP waste acceptance criteria, gas generated in the vented drums by a combination of metal corrosion and microbial activity will probably build up in the repository. Gas pressure could reach the point at which it will push outward on the surrounding salt bed;[33] developments beyond that are matters for both analysis and speculation. The analysis is being done by DOE's Sandia National Laboratory (SNL), the principal scientific contractor for the WIPP operation. Speculation at a March 1990 meeting of WIPP advisory and oversight groups convened by the National Academy of Sciences ranged from an optimistic "hoop stresses will hold things together" to a pessimistic "radioactive materials will be released into the environment."

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[29] The purpose of the Environmental Evaluation Group (EEG) is to conduct an independent technical evaluation of the Waste Isolation Pilot Plant (WIPP) Project to ensure protection of the public health and safety and the environment. The EEG was established in 1978 with funds provided by the U.S. Department of Energy (DOE) to the State of New Mexico. Pub. L. No. 100-456, the National Defense Authorization Act, FY 1989, Section 1433, assigned EEG to the New Mexico Institute of Mining and Technology and provided for continued funding from DOE through a contract (DE-AC04-89AL58309).

[30] R.H. Neill, Environmental Evaluation Group, paper presented at Waste Management Conference, Tucson, AZ, February 1989.

[31] R.H. Neill, Environmental Evaluation Group, letter to Jack B. Tillman, U.S. Department of Energy, WIPP Project Office, Carlbad, NM, Apr. 7, 1989.

[32] R.H. Neill, Environmental Evaluation Group, personal communication to R.P. Morgan, May 1990.

[33] According to a 1989 Sandia report, gas pressure in the mine could increase to a "lithostatic" pressure of 2,150 pounds per square inch in 65 to 70 years (30).

A June 1990 report of Sandia National Laboratory concluded that *"SNL has reasonable confidence that compliance is achievable* with the (EPA disposal) Standard as first promulgated."[34] However, the report goes on to state that it is "not a formal evaluation of compliance; available data and models are insufficient for a full-scale assessment." According to the report: "The major question remaining is not whether the WIPP can comply with the Standard but rather how it should comply." Among the options being examined for how to comply are identification of alternatives for the waste form and repository design to improve WIPP's ability to reduce potential releases.

OTA has not analyzed the Sandia Report in detail. The Environmental Evaluation Group finds the report's primary deficiency to be that "it does not present analyses of breach scenarios involving gas pressurization in the repository. Since the experiments with the waste focus on measuring the rate of gas generation, it is necessary to present analysis of breaches involving this phenomenon, including a determination of the threshold of unacceptable gas generation rate and an assessment of the likelihood of meeting compliance with the standards with or without planned modifications."[35] As a consequence of this and other aspects of the report, EEG finds that the report does not provide "sufficient basis for high confidence that WIPP can demonstrate compliance with the . . .. Standards."

Another aspect of the Sandia Report is troubling. In the foreword, it is argued that although some readers may disagree, Sandia's positive finding of "reasonable confidence that compliance is achievable without demonstrating compliance" is "logical and must be made at this time." The reason given is that predictions of feasibility are essential for R&D projects and must invariably anticipate achieving project objectives. "National Air and Space Administration was able to predict the achievability of a manned moon landing years before they could demonstrate it. Had realistic predictions of ultimate success not been available in advance, the task might never have been undertaken." What is troubling about the NASA analogy is that it equates a relatively high-risk task in space exploration with a task that seeks to ensure the safe disposal of radioactive and hazardous wastes in a manner that minimizes risk to the public and the environment—two very different activities with very different levels of public support and understanding. Furthermore, this philosophy clearly indicates Sandia's role in support of the objectives of the DOE mission; thus, Sandia's conclusion of compliance with the standard, no matter how soundly based, is likely to be questioned. A related question is whether or not there is sufficient independent oversight and analysis capability outside of DOE and its contractor network to scrutinize such analyses and perform them independently, primarily from the viewpoint of public health and safety.

Two approaches might be hypothesized to deal with the problem of gas generation that illustrate the range of possible choices. One is to stay with the current waste form, learn as much as possible about gas generation, assuming that compliance with disposal standards can be demonstrated. The other is to alter the waste form now to reduce or even eliminate the generation of gas; processes for this range from shredding, compaction, and grouting on one hand, to incineration, calcining, or vitrification on the other.[36] As mentioned previously, the latter alternatives could be very disruptive of current DOE plans and could add considerably to the cost and the occupational risk.

Studies of alternative engineering waste forms are part of DOE's decision plan for WIPP. DOE appears to be pursuing somewhat of a middle course in that although we know of no firm plans as of this writing to test alternative waste forms in or for WIPP, such forms represent a fall-back position in case the untreated waste form does not comply with the Standard.

An Engineered Alternatives Task Force (EATF) has been created by International Technology Corp. for Westinghouse, the management and operating contractor for WIPP. The EATF has made preliminary recommendations of 15 possible waste-form treatments for inclusion in WIPP's test program. Six basic forms on the list include glassified vitrified waste, cemented waste, compacted waste, shredded waste with bentonite filler, metal waste melted into ingots, and pH-buffered waste packages. Final recommendations are due in 1991.[37]

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[34] S.G. Bertram-Howery, and P.N. Swift, "Status Report: Potential for Long-Term Isolation by the Waste Isolation Plant Disposal System," Sandia Report SAND90-0616, Albuquerque, NM, June 1990.

[35] R.H. Neill, EEG, letter to L.P. Duffy, DOE Aug. 24, 1990.

[36] Eliminating steel drums would avoid anoxic corrosion.

The gas generation issue is central to current thinking about the WIPP experimental phase. DOE wishes to move ahead with a series of bin experiments in which gas generation rates will be measured in the repository with real TRU waste. Objections to these experiments include the following: previous measurements indicate that gas generation rates will be unacceptably high; the experiments can be done outside the repository; and WIPP was not designed for handling liquid samples with radioactive transuranics. Counterarguments for moving ahead include: if the experiments are performed outside of WIPP, it will be argued that they were not done under real-world conditions; and WIPP exists, so it is cheaper and better to do the bin experiments there than elsewhere.

Alcove experiments to test gas generation and brine inflow in somewhat larger spaces are also planned. The bin and alcove experiments will employ about 0.5 percent of all of the waste eventually destined for WIPP, roughly 4,500 waste drums or 100 TRUPACT trailers full of waste. As of June 1990, a proper seal for the alcove experiment had not been achieved.[38] Finally, in April 1990, DOE indicated that, at EPA's suggestion, it would evaluate the possibility of filling two rooms with waste during the test phase, raising the possible emplacement from 0.5 to 2 percent of design capacity and from 100 to 400 TRUPACT trailers.[39]

Disposal Standards; "No Migration"; Land Withdrawal—Two other aspects of WIPP that deserve examination are its performance assessment and its ability to meet EPA disposal standards for TRU waste. At present, assessment of the performance of WIPP is not expected to be completed before the end of 1994. This assessment is likely to be important in determining whether or not WIPP will meet the EPA disposal standards and whether the waste form will have to be changed in order to do so. DOE hopes to proceed with the experiments without having to demonstrate compliance with EPA disposal standards, arguing that the standards should apply only to the operational phase; EPA concurs with this. The relevant EPA standards have been remanded by the courts, and new standards are not expected to be finalized before 1992. At a March 1990 meeting of four WIPP oversight committees, concern was expressed about the ability of WIPP to meet the standards under a human intrusion scenario; although less concern existed about a undisturbed scenario, there was concern nevertheless.[40]

An important step toward proceeding with the WIPP experimental phase occurred when EPA proposed to rule positively on DOE's request for a no-migration variance that would allow emplacement of mixed TRU waste in WIPP for "testing and experimentation to determine whether the site is appropriate for the long-term disposal of mixed waste" (90). The proposed EPA ruling, which was followed by a 60-day public comment period,[41] prohibits DOE from moving ahead with the operational phase and requires it to remove the waste if a "no-migration" condition of hazardous waste cannot be demonstrated for the long term (90). The proposed ruling indicates that EPA basically supports DOE efforts at WIPP.[42] According to EPA, "Given the geologic stability of the area; the depth, thickness, and the very low permeability of the salt formations in which the repository has been mined; and the properties of rock salt as the encapsulating medium . . . the WIPP is a promising site for a permanent mixed-waste repository'' (90). In November 1990, EPA approved DOE's WIPP no-migration petition for the test phase, but imposed several conditions (see app. A).

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[37] S.G. Bertram-Howery, and P.N. Swift, "Status Report: Potential for Long-Term Isolation by the Waste Isolation Plant Disposal System," Sandia Report SAND90-0616, Albuquerque, NM, June, 1990.

[38] Subsequently, in October 1990, DOE informed EEG that these tests are not scheduled to start until 1992. They will not be carried out unless an adequate seal can be demonstrated. (See R.H. Neill, EEG, testimony before New Mexico legislative Committee on Radioactive and Hazardous Materials, Carlsbad, NM, Oct. 4, 1990.)

[39] Senate Energy Committee, hearing on WIPP, Apr. 3, 1990.

[40] National Academy of Sciences meeting on Public Confidence in WIPP, Mar. 5, 1990.

[41] Among the comments was a joint submission by The Attorney General of Texas, the Hazardous Waste Treatment Council, and four environmental organizations opposing the proposed variance. (See "Joint Comments on the Proposed Conditional 'No-Migration' Variance From Land Disposal Restrictions to the Department of Energy's Waste Isolation Pilot Plant," submitted by the Natural Resources Defense Council, The Hazardous Waste Treatment Council, The Attorney General of Texas, Southwest Research and Information Center, Concerned Citizens for Nuclear Safety, and the Environmental Defense Fund, June 5, 1990.)

[42] Some concern has been expressed that EPA was too accommodating to DOE pressure and too hasty in its favorable response to the no-migration petition. In addition, Representative Mike Synar of Oklahoma has criticized EPA for proposing to grant the variance without having disposal standards in place. (See "Synar Says EPA Pressured To Waive Rules," Associated Press News Release, May 9, 1990.)

One hurdle that still remained as 1991 began was withdrawal of the land on which WIPP is located from the public domain. DOE had been pursuing two options in this regard: the preferred option was for Congress to pass a law authorizing such land withdrawal; the other was for the land withdrawal to be handled administratively by the Department of the Interior. However, as Secretary of the Interior Manuel Lujan pointed out, such administrative withdrawal would be for only 20 years; at the end of that time the land would have to be restored to its original condition.[43] Such restoration would be a nearly impossible requirement for a fully operational long-term geologic repository to meet, but it would be sufficient for the test phase for which the waste must be retrievable.

A land withdrawal bill that presumably reflected DOE's position was introduced in Congress during 1990. This legislation placed certain conditions on DOE, some of which had been met (e.g., completion of the Supplemental Environmental Impact Statement) or were in the process of being met (e.g., granting of the no-migration variance).[44] Benefits to the State of New Mexico include the use of local workers and the potential development of local businesses, as well as DOE payments to local governments in lieu of taxes that would have accrued if the land were privately owned (90).

Conditions in the land withdrawal bill seemed to provide DOE with some leeway to move beyond the experimental phase. There was no limit on the volume of waste that could be placed in WIPP; restraints to doing so appear to be mainly verbal assurances from the Secretary of Energy (90). Land disposal legislation could serve as a vehicle for imposing additional conditions on DOE. However, no such legislation was passed during 1990. In January 1991, the Department of the Interior transferred control of 16 acres including WIPP to DOE by the process of administrative withdrawal.[45]

At present, DOE is pushing vigorously to get the first waste for the experimental phase into WIPP. The symbolic value of emplacement of the first waste package could be of equal or greater value than specific technical information likely to emerge from this phase. DOE's technical oversight groups generally support proceeding with the bin and alcove experiments, although substantial sentiment exists in EEG for moving ahead with plans to alter the waste form to reduce or eliminate gas generation and make the waste package more analogous to that for high-level waste, given the parallel disposal approaches for these two categories implied by EPA standards.[46] If the experimental phase is initiated, the performance assessment, including analysis of whether an operational WIPP repository can meet EPA long-term disposal standards not yet promulgated, will be very important during the next 3 or 4 years. The following issues could arise if waste is placed in WIPP before disposal standards are in place.

Analysis of Storage Issues at WIPP—In December 1989, the General Accounting Office (GAO) reviewed DOE's proposed experiments and storage operations at WIPP, in response to a request from Representative Mike Synar prompted by the discovery of brine in what was expected to be a dry repository. GAO summarizes its results as follows (45):

> WIPP is a key part of DOE's plan to clean up its aging defense facilities. By moving TRU wastes from these facilities to WIPP, DOE would be able to address what has become a contentious issue in federal-state relations—continued ''temporary'' storage of the wastes. However, by storing waste in WIPP years before determining compliance with disposal standards that are as yet uncertain, DOE might have to either abandon WIPP, if it does not comply with the new standards, or remove and/or rehandle wastes in order to comply with the standards. In making a decision on DOE's request to withdraw the land and permit storage to begin, the Congress' choices range from authorizing waste storage in WIPP either with or without restrictions to deferring action until DOE has determined that WIPP complies with EPA's revised standards. The Congress needs to weigh several factors:

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[43] Secretary of the Interior Manuel Lujan, testimony at hearing on WIPP before Senate Energy Committee, Apr. 3, 1990.

[44] The no-migration variance for WIPP was published by EPA in the *Federal Register* on Nov. 14, 1990. The determination to allow DOE to dispose of RCRA-regulated hazardous constituents at WIPP will be limited to testing and experimentation purposes for a period of 10 years.

[45] K. Schneider, ''Plan on Starting Nuclear Waste Clears Big Hurdle,'' *The New York Times*, Jan. 23, 1991.

[46] EEG recommended pursuing only the bin and alcove experiments, not the ''two-room'' or operations demonstration, until DOE proves it can meet the disposal standards.

—If WIPP does not comply with EPA's standards, DOE would either have to remove the wastes from the site, retrieve them for additional processing, or rehandle them to modify the facility and achieve compliance. DOE, however, has not addressed these contingencies in its draft test plan.

—DOE could defer a demonstration of waste storage operations. Deferring the demonstration, however, would delay DOE's removal of TRU waste from other facilities, and states hosting these facilities vigorously oppose additional storage at the facilities.

—The National Academy of Sciences agrees that DOE's planned-gas generation experiments are warranted and should begin but recommends deferring the demonstration of storage operations.

GAO recommended that DOE provide Congress with three categories of information: technical justification for waste storage in WIPP, including the amount to be stored, "in advance of determining if the facility can be used as a repository'; contingency plans for disposing of waste, experimental or operational, stored in WIPP if the facility does not comply with EPA disposal standards;[47] and options for continuing to store waste at other Weapons Complex sites while DOE assesses WIPP's compliance with standards. GAO also suggested that Congress consider: including a provision in any eventual legislation limiting the amount of waste that could be stored at WIPP until compliance with the standards is achieved; and making permanent land withdrawal for WIPP conditional upon a positive determination of compliance with standards.

The Future of Plutonium Operations at Rocky Flats

According to reports early in 1990, DOE was committed to repairing Building 371 at Rocky Flats, which was opened in 1981 to replace two older facilities (Buildings 771 and 776) and then shut down in 1984 (40). Building 371 has been plagued with problems from the outset; evidently, up to $600 million will be required to make the necessary repairs and additions.

Rocky Flats is the only "source of the plutonium parts that trigger thermonuclear reactions" (40). Arguments for the repair of Building 371 are that existing facilities are getting old, that Rocky Flats is the only place currently reprocessing old warheads (a necessity even with arms control agreements), that plans for a Special Isotope Separation (SIS) plant for plutonium isotopes at Idaho have been abandoned by DOE at least for now, and that opposition exists to the idea of expanding plutonium operations at Los Alamos from research to production. On the other hand, Colorado Senator Tim Wirth has expressed the case against renovating Building 371 as follows: "The idea of extending the life of a plutonium processing plant in the middle of a major metropolitan area makes absolutely no sense. We are not exactly living at the height of the cold war. What is the rush to build a new facility at Rocky Flats?" (40)

Of immediate concern is whether it will be safe to restart the Rocky Flats Plant after a shutdown for repairs, safety inspections and evaluation, and management changes that began in November 1989. One of the concerns is whether the plant will be allowed to reopen with some or all of the 28 kilograms of plutonium dust in the vents and ducts (38). DOE has stated that the plant will not reopen until it can do so safely; in making this assessment, DOE is receiving input from the Defense Facilities Nuclear Safety Board. However, Congresswoman Patricia Schroeder of Colorado has expressed concern that pressure was being exerted by the defense establishment to restart the plant promptly.[48] This debate illustrates the tension between perceived defense production needs on one hand and environmental or safety concerns on the other.

In a report on modernizing the DOE Weapons Complex submitted to Congress in January 1989, DOE suggested eventually shutting down Rocky Flats and moving its operations to another weapons site. This subject was subsequently reviewed in a September 1989 OTA report (46). More recently, in January 1991, DOE issued a report that supersedes its earlier study and proposes reconfiguring the Weapons Complex into one that "would be smaller, less diverse, and less expensive to operate than the Complex of today."[49] In the Reconfiguration Study, relocation of the Rocky Flats Plant is a preferred option of the Secretary of Energy although the time frame for the relocation is not specified and restart prior to relocation is anticipated. Although no reactor production of plutonium is required for any of the weapons stockpile scenarios considered in the study, DOE deems "a modern plutonium recycle and recovery capacity to be essential to extract plutonium from retired weapons and to minimize wastes.[50] As DOE continues to study the question of modernizing the Weapons Complex and building new facilities or moving certain functions, it will need to consider carefully the implications for safe waste disposal in the future.

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[47] In Nevada the NRC requires DOE to show compliance with long-term disposal standards for high-level waste *before* receiving a license to begin construction of the Yucca Mountain repository. This requirement exists even though it is very likely that disposal standards will be in place long before a HLW repository opens.

[48] Congresswoman Patricia Schroeder, testimony at hearing of Defense Nuclear Facilities Safety Board, House Committee on Armed Services, Mar. 22, 1990.

[49] U.S. Department of Energy, Nuclear Weapons Complex Reconfiguration Study, Report DOE/DP-0083, January 1991, Foreword.

TECHNOLOGIES FOR IMPROVED MANAGEMENT OF TRANSURANIC WASTE

Introduction

This section discusses three treatment technologies that could prove useful for managing retrievably stored TRU waste—incineration, immobilization in grout or concrete, and compaction—as well as one technology for managing buried TRU waste, namely, in situ vitrification. The purpose of improved treatment technologies is to reduce some or all of the following TRU waste characteristics: solubility, respirability, mobility, volume of gas produced, volume of waste, and uncertainty in predicting its behavior in a repository. The three technologies discussed are receiving considerable attention because of their potential or proven utility. One of these, incineration, also tends to be visible because it often meets with public opposition. In situ vitrification probably receives more attention within the Department of Energy (DOE) than any other technology as a relatively new, innovative approach for in-place immobilization of buried waste. DOE's plans for overcoming problems in the management of TRU waste are also outlined in this section. Finally, actinide conversion (transmutation) and waste minimization, as they pertain to TRU waste, are discussed.

Three Technologies for Treating Retrievably Stored Transuranic Waste

Incineration

Incineration (i.e., the burning of hazardous or radioactive materials) is potentially very useful for reducing waste volume and destroying the hazardous component of mixed waste. Because the hazardous component is often an organic material, incineration can greatly reduce or eliminate gas buildup in a repository caused by the radiolysis of organic compounds and bacterial decomposition.[51] Furthermore, the ash from incinerated waste lends itself to immobilization by incorporation with cement into grout or concrete. In addition, incineration as a treatment method has been approved for certain uses by EPA. However, DOE has encountered both technical and regulatory (licensing) problems with some incinerators already constructed. In addition, incinerators unrelated to DOE Weapons Complex activity have been opposed by citizens groups in various communities. As a result, DOE seems to be somewhat wary of incineration as a future waste treatment method.

Table 2-4 summarizes the TRU waste incinerators in the Nuclear Weapons Complex. None of these incinerators is currently operational as of late 1990.

According to Benedict et al. (13), "concentration of burnable solid waste can be very effectively achieved by incineration. The ashes are handled as radioactive waste. This is a rather costly technique because of much effort spent for off-gas filtration and safe handling of the ashes. . . . A much simpler technique is baling of the waste under high pressure." The latter reference is presumably to *compaction* and "supercompactors," discussed below. Unlike incineration, compaction or immobilization in grout or concrete does not destroy hazardous components. Finally, these authors suggest complete decontamination of large, bulky equipment that is contaminated at the surface by rinsing with acids or other solvents, ultrasonic treatment, and sandblasting. There remains, however, the question of what to do with the radioactive solvent or dust generated during decontamination.

Some specific DOE experience with incinerators at Weapons Complex sites designed for use with TRU waste is now reviewed.

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[50] Ibid., p. 65.

[51] These two components account for about half of the total gas generated. The rest is the result of metal corrosion.

Table 2-4—Summary of Transuranic Waste Incinerators at DOE Weapons Complex as of July 1990

Site[a]	Name[b]	Type	Start[c]	Feed type[d]	Status
Hanford Plant	WRAP	Plasma arc	1999	T	Planned
INEL	PREPP	Rotary kiln	1985	L, T, R, M	Testing
INEL	WED	Plasma arc	1996	L, T, R, M	Proposed
LANL	CAI	Controlled air	1976	L, T, R, P, M	Standby
Rocky Flats Plant	FBU/PP	Fluidized bed	1974	L, T, R, P	Standby
Rocky Flats Plant	FBU/PROD	Fluidized bed	1978	L, T	Standby
Savannah River Site	PWI	Wire conveyor	1986	T	Standby

[a] INEL = Idaho National Engineering Laboratory; LANL = Los Alamos National Laboratory.

[b] WRAP = Waste Receiving and Processing Facility; PREPP = Process Experimental Pilot Plant; WED = Waste Engineering Development Facility; CAI = Controlled Air Incinerator; FBU/PP = Fluidized Bed Unit/Pilot Plant; FBU/PROD = Fluidized Bed Unit/Production; PWI = Plutonium Waste Incinerator.

[c] Future start dates are estimated.

[d] Feed type code: L = low-level waste; T = TRU waste; H = high-level waste; R = Resource Conservation and Recovery Act waste; P = Toxic Substances Control Act waste (polychlorinated biphenyls); M = mixed waste.

SOURCE: Office of Technology Assessment, 1991.

The Process Experimental Pilot Plant (PREPP) at the Idaho National Engineering Laboratory (INEL) was "to demonstrate full-scale methods for processing the uncertifiable stored TRU waste into a form acceptable at the WIPP [Waste Isolation Pilot Plant]" (28). Rotary kiln incineration is one of several steps that include low-speed shredding and immobilization by cementing.[52] PREPP was built and underwent debugging after some initial tests. DOE had many technical problems with the process and as of September 1989, PREPP was a year or so away from completion and further testing. The rotary kiln incinerator appears to be primarily responsible for the delays encountered in the startup of PREPP. Both technical and regulatory obstacles must be overcome before operation can begin. In late 1990 it was uncertain when or whether PREPP will become operational.

PREPP has an elaborate off-gas system for the kiln that includes a quencher, venturi scrubber, entrainment eliminator, mist eliminator, reheaters, and HEPA (high-efficiency particulate arrestor) filters.[53] The system is necessary because after final filtration by two banks of HEPA filters, the off-gas will be released from the stack. Hot ash and other inert materials from the kiln will be separated and then grouted with cement in drums.

The Controlled-Air Incinerator (CAI) at Los Alamos has burned both radioactive (TRU) and chemical wastes in an experimental mode and has been modified for future use to burn TRU waste on a continuing operational basis, subject to preparation and approval of an Environmental Impact Statement. The CAI is licensed to burn polychlorinated biphenyls (PCBs) under the Toxic Substances Control Act (TSCA), and in November 1989 received a Resource Conservation and Recovery Act (RCRA) permit to burn hazardous waste. The primary combustion chamber (PCC) of the incinerator can accept up to 125 pounds per hour of solid waste or 200 pounds per hour of liquid waste (32). An elaborate off-gas system is said to reduce radioactive emissions to well below permissible limits under the Clean Air Act.[54] Plutonium throughput is limited because some of the processing vessels do not have the intrinsically safe geometry needed to prevent criticality accidents. No good estimates appear to be available on incineration costs during future operations.

The question of what to do with the ash after incineration is still being explored. Immobilization in cement may not be viable if cadmium or lead is present because the leachability may be too high. One alternative is microwave vitrification of the ash; such a process is being developed in Japan. A regulatory issue still to be resolved concerns some limitations that the State of New Mexico has placed on air emissions, which DOE contends should not be subject to State regulation. Finally, the incinerator at Los Alamos National Laboratory (LANL) has been a source of considerable concern to some members of the community, and certain efforts by LANL to win support for the incinerator may have had the opposite effect (23).[55]

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[52] As an alternative to cementing, research is proceeding on a plasma reactor that could turn waste into unleachable rock. A demonstration test of the plasma reactor is being conducted in Butte, MT under the sponsorship of DOE, the EPA Superfund Innovative Technology Evaluation (SITE) program, and a private company, RETECH; tests were scheduled to be completed by 1991.

[53] Some problems associated with the use of HEPA filters have been described (27).

[54] D. Hutchins, briefing during visit to Los Alamos National Laboratory, Mar. 27, 1990.

Plans for incineration of low-level mixed waste at *Rocky Flats* in a *fluidized-bed incinerator* have met with considerable opposition. By 1988, 10 city councils had gone on record as opposing a trial burn with the incinerator, and a lawsuit had halted its use (22). Allegation of illegal use of the incinerator was one element that prompted a 1989 raid by the Federal Bureau of Investigation on Rocky Flats (88). This particular situation is not pursued further here because the incinerator in question is for low-level, not TRU, waste. However, the situation at Rocky Flats illustrates the depth of resistance to be expected when incineration is raised as a treatment option. Also, the residue from incineration, the ash, may well be TRU waste even if the input to the incinerator is not.

Immobilization in Grout or Concrete[56]

The range of products for immobilizing TRU waste is wider than for high-level waste (HLW) because heat generation will be significantly less. Possibilities include glass, cement, bitumen, and polymers. Hydraulic cement has been used for many years.[57] Additives to improve setting properties and fission product retention include sodium silicate. Polymer impregnation of cement is also being developed. Benedict et al. conclude that "in spite of experience, solidification with cement is still an art. Each new waste application must be considered individually because of possible interactions between cement and the waste constituents" (13).

Bitumen, or asphalt, is another possibility. It is "highly leach-resistant, it has good coating properties, and it possesses a certain degree of plasticity" (13). An advantage of bitumen over cement is that it permits almost total removal of water through evaporation, resulting in a volume reduction up to fivefold greater than cement. The disadvantages of bitumen compared to cement include its potential fire hazard and its tendency to release hydrogen and other gases in a radiation environment (13).

For TRU waste of high radioactivity, glass may be the immobilization medium of choice (13). It has superior radiation stability, and its leach rates are lower than for cement. It is the most expensive choice, followed by bitumen and then cement, but because large-scale vitrification facilities are coming on-line, the marginal cost of immobilizing some TRU waste ash by vitrification, particularly remote-handled TRU waste, might be acceptable. Although TRU waste volumes are large, incineration results in a volume reduction of the order of 100:1 (32).

Current DOE plans for treatment of TRU waste include some immobilization in grout or concrete, although such immobilization is not a general requirement for the acceptance of waste packages at WIPP. Some concerns about immobilization in concrete or grout include the following: What is the longevity of the grout? How long will it retain its structural integrity? How long will it keep the transuranics, as well as any hazardous components, fixed in place and isolated from the environment? What reactions, if any, will take place between the grout and the container?

Compaction

Compaction reduces waste volume by compressing dry solid waste into disposal or shipping containers (18). In general, it has been used more widely in the commercial sector than at DOE sites, primarily for LLW. Supercompaction also appears to be in favor in the European commercial nuclear industry, bringing about LLW volume reduction ratios ranging from 3:1 to 10:1 (36). Recent concerns about storage limits for mixed waste have sparked interest in compaction at DOE.

One limitation of compaction is that the process tends to concentrate radionuclides. Care must be exercised to ensure that the final waste package does not exceed the radioactivity limits of the particular waste category. For TRU waste, there is an upper limit to the radioactivity of waste packages under current WIPP acceptance criteria. Also, plutonium concentrations must not exceed those at which criticality becomes a concern.[58]

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[55] Ibid.

[56] Concrete is generally defined as a hard substance made of sand, gravel, cement, and water. Grout is normally defined as a thin mortar used to fill chinks or cracks. Grout, concrete, and "saltstone" are used interchangeably by DOE; sometimes a specific term refers to a particular site. They all refer to products formed by immobilizing waste with cement and various other constituents.

[57] The British are very positive about the use of "cements," i.e. concrete. (Source: R. Webster, United Kingdom Atomic Energy Authority, personal communication, Dec. 15, 1989.)

[58] For remote-handled TRU waste, WIPP waste acceptance criteria limit radioactivity to 23 curies per liter, or about 5,000 curies per 55 gallon drum. Containers are limited to 1,000 plutonium-equivalent curies each, and drums cannot have more than 200 grams of fissile material (69).

A "supercompactor" that received considerable attention in 1989-90 is being readied for operation at Rocky Flats. Because of a limit imposed by the State of Colorado on the *volume* of TRU mixed waste that can be temporarily stored at Rocky Flats, DOE plans to employ compaction in an effort to defer the date on which that limit is exceeded. According to a General Accounting Office (GAO) report, a Rocky Flats official estimated that the supercompactor would reduce by 50 percent the volume of TRU mixed waste generated and stored on-site (44).

The Rocky Flats supercompactor was planned to begin operating in the fall of 1990. However, delays occurred due to both regulatory and technical obstacles. On the technical side, supercompactor components were purchased from several international vendors and had not been tested as a unit. Connection of a glove box to a supercompactor was to be done for the first time; however, the supercompactor press was dropped during shipment from West Germany and found to be rusted, with some electrical wiring vandalized (44). However, DOE reportedly believed that the physical condition of the supercompactor would not be a limiting factor in moving ahead with installation and operation (89). After an environmental assessment (89), a 30-day period of public comment followed. DOE issued a proposed "Finding of No Significant Impact" (FONSI) for construction and operation of the Rocky Flats Supercompactor and Repackaging Facility and the Transuranic Waste Shredder.

In August 1990 it was reported that DOE had approved plans for "a new high-tech waste shredder and compactor" for use at Rocky Flats—presumably the same device described previously. Operation of the device is now planned for early 1991 and is expected to extend Rocky Flats mixed TRU waste storage capacity by up to 18 months if Rocky Flats Plant plutonium processing operations are resumed. The shredder is reported to pulverize graphite molds and filters while the compactor reduces drums of waste to cylinders about 20 inches in diameter and up to 18 inches thick.[59]

The history of the Rocky Flats supercompactor to date would indicate that DOE has not devoted enough resources to the use of this technology at weapons sites. Given the storage situation as it evolved at Rocky Flats, some kind of compaction equipment should have been available or should have been acquired from other DOE sites; evidently, this was not possible.

Shredding and compaction represent the next level of treatment that might be considered as an alternative to the essentially untreated TRU waste packages currently destined for WIPP. Treatment costs should be considerably lower than for incineration. Although such treatment would reduce waste volume by a factor of five or so, it might not significantly retard the rate of gas generation; in fact, the shredding and compaction process could conceivably enhance it. Experiments with this waste form are needed.

In Situ Vitrification

A great deal of interest has been generated in the use of in situ vitrification (ISV) as a technology for immobilizing buried waste or contaminated soil. A high current flowing through giant electrodes, in or near the media to be vitrified, melts the material, which then hardens into a glasslike solid. The technique was pioneered at Hanford by Battelle's Pacific Northwest Laboratory with DOE financial support. Battelle then obtained a license for the rights to ISV technology and created the Geosafe Corp. to commercialize the process (24,26). Geosafe's license seems to focus on the use of ISV for hazardous waste sites. Demonstrations at Weapons Complex sites are being carried out by DOE and its contractors.[60]

The advantages of ISV include vitrification of soils up to a depth of 30 feet, destruction of organics and incorporation of heavy metals into the vitrified mass, complete dissolution of cement inclusions within the vitrified mass, and more modest off-gas system requirements than incineration.[61] Perhaps the greatest potential advantage is the prospect of immobilizing buried waste, thereby eliminating the need or cost of exhumation, treatment, transport, and disposal, as well as the health risk to workers involved in these operations. Some consideration is also being given to immobilizing drum and tank waste by using ISV (24).

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[59] "DOE Approves Plan for Waste Compactor at Rocky Flats," Associated Press News Release, Aug. 16, 1990.

[60] Koegler, S., Battelle Pacific Northwest Laboratory, remarks at Office of Technology Assessment Workshop on Soils and Groundwater Remediation Technologies, May 8, 1990.

[61] Ibid.

Areas requiring further investigation include the economics and possible safety or health hazard from ISV. According to DOE personnel, in situ vitrification requires relatively dry soil and energy costs of 1.5 to 2 cents per kilowatt-hour, to be economically feasible.[62] A cost of about $250 to $350 per ton is estimated for most vitrification operations (24). Unanswered health and safety questions include performance of the off-gas system and possible worker hazards from strong electric fields.

The first full-scale test of in situ vitrification of mixed waste is underway at Hanford. During April 1990, researchers intended to melt in place the contents of a waste crib and the soil surrounding the crib in the 100-B area, a high-priority site for cleanup under the Hanford tri-party agreement. After the 9-day test, about a year would be required for the molten waste to harden into an 800-ton mass (28).

Preliminary results of the Hanford mixed waste ISV test were reported at a May 1990 Office of Technology Assessment (OTA) workshop.[63] Although plans were to melt down to a depth of 20 feet, the test was halted at a depth of 14 feet because of concern that the horizontal spread of the melt would exceed the limits of the hood that collects off-gases. Roughly 75 percent of the hazardous materials in the waste crib and 50 percent of the radioactive materials in the crib were reached. The full-scale demonstration used three semitrailers and is capable of melting 3 to 5 tons per hour. In this mixed waste test, the radionuclides were strontium and cesium. An earlier full-scale test was performed about 2 years ago on a trench in which plutonium solutions had been dumped. That test reached a depth of 15 feet.

The ISV mixed waste test cost about $1.8 million, with about one-third of that needed for environmental documentation and characterization.[64] The cost of the 9-day melt period was estimated at about $250,000. Total costs to date for the development of in situ vitrification are on the order of $10 million.

The following evaluation of ISV was offered at the May 1990 OTA workshop: It is effective near the surface and ready for use on radionuclides and heavy metals in shallow land burial sites. Hopefully, in a few years, it will be available for use on Hanford single-shell tanks,[65] after they are filled with soil. The glasslike product is more leach resistant than the melt from the HLW vitrification process because melt temperatures are higher. Some limitations include the depth to which a melt can be carried out and the water or moisture content of the soil; high moisture content increases the energy costs. ISV should be roughly comparable in cost to exhumation and treatment, and should be very effective on tough mixtures. Furthermore, it minimizes worker radiation exposure compared with removal and treatment of the waste. However, ISV is not a solution for all the buried waste and contaminated soil at all DOE sites. It should be applied selectively to the worst "hot spots."

Some issues discussed, but not necessarily resolved, at the OTA workshop were the following: How good are the off-gas systems used in connection with in situ vitrification? Can the ISV process lead to further contamination outside the melt zone? Is ISV likely to be acceptable to local communities and citizens who may expect to have the waste physically removed? What are the prospects for ISV now that the Geosafe process has been accepted in the Environmental Protection Agency (EPA) Superfund Innovative Technology Evaluation (SITE) program?

In October 1989, the first INEL field test of in situ vitrification was carried out. This test, which was on a scale about one-tenth that of Hanford,[66] involved movable electrodes, an off-gas containment hood made of fabric rather than metal so that equipment could be transported by truck, and simulated TRU waste with high buried metal content and high buried combustible content, but without radioactivity. Below the electrodes were both stacked drums and randomly dumped drums and boxes of waste.[67] This intermediate-scale ISV test was aborted because the fabric hood was "glowing" and flames were present. Simulated waste buried deeper than 24 inches showed no evidence of heat damage, and glass splatter around the melt zone was uneven.[68] After review of the system and revision of procedures and equipment, a second test was reported to have been completed successfully in 1990, with a metal rather than a fabric hood.

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[62] L. Duffy, U.S. Department of Energy, remarks at special meeting of OTA Advisory Panel, Mar. 1, 1990.

[63] S. Koegler, op. cit., footnote 10.

[64] Ibid.

[65] In September 1990, Battelle Pacific Northwest Laboratories began what was described as the "first field test to collect data to determine whether ISV can effectively be used on tanks and their contents." The tank contained hazardous waste but no radioactive component. (See "PNL Halts In Situ Vitrification Test on Mock Tank Containing Wastes," *Report on Defense Plant Wastes*, Sept. 14, 1990.)

[66] Ibid.

[67] J.L. Landon, "In Situ Vitrification Update," presentation to National Academy of Sciences Panel on Buried Wastes at INEL, Nov. 13-14, 1989.

The Applied Research, Development, Demonstration, Testing, and Evaluation Plan (RDDT&E)

The draft DOE RDDT&E plan of November 1989 singles out three "specific needs" to overcome problems in TRU waste management, in addition to opening WIPP for its 5-year demonstration period. These include the need for "better TRU waste treatment to meet WIPP certification requirements," "better characterization of RCRA components in TRU waste for certification," and "disposal options for TRU waste not certifiable for WIPP" (47).

In the area of TRU waste treatment, wastes for which treatments must be demonstrated include "resins and sludges that release water during storage, organic waste forms that generate excessive gas, and reactive metals such as sodium and sodium/potassium mixtures." Technologies of interest to DOE for treating noncertifiable TRU waste include "microwave melting, plasma decomposition, smelting, denitration, dehalogenation, incineration with the resulting ash solidified by cementation or in-can melting, and chemical oxidation by nitrate salts" (48). Concreting or grouting and reactive metal neutralization are also of interest.

In the characterization area, the DOE RDDT&E plan indicates that technologies are needed to better characterize the containers of stored TRU waste, which can be found at most sites, for their hazardous RCRA components, as well as to determine which are and which are not TRU waste. According to the report, the "technologies to be used in this area have not been identified'; DOE is in the review and survey stage (49) (see figure 2-10).

Waste that is noncertifiable for WIPP will have to be disposed of elsewhere in other ways; such waste includes oversized packages, large pieces of equipment, waste containing high explosives, and certain classified waste. DOE is working on a technology called Greater Confinement Disposal (GCD) at the Nevada Test Site (NTS); this involves placement in a deep hole, as an alternative to WIPP disposal for noncertifiable TRU waste. GCD has been used at Savannah River and Oak Ridge for some Greater-than-Class C LLW (50). It has been undergoing evaluation at NTS with the goal of compliance with EPA standards (40 CFR 191) for management and disposal of HLW and TRU waste (50).

The RDDT&E plan focuses explicitly on some aspects of TRU waste management for retrievably stored waste; research and development for buried TRU waste are addressed indirectly. For example, although buried TRU waste at Idaho is mentioned as an example of a particular problem to be solved (51), it is not singled out as a distinct category. Nevertheless, buried waste will clearly benefit from research on the "Problems in Remediating Contaminated Soils," which is part of the plan (52).

One aspect that needs more work is setting priorities for technologies that might be useful rather than simply listing them. There is little information in either the 1989 RDDT&E plan or the 1990 Five-Year Plan that would help distinguish between what is being funded and what is not. Also WIPP is considered to be outside these plans because it has already been built and a 5-year demonstration phase is planned. Nevertheless, research is needed on gas generation in alternative TRU waste forms for WIPP, as well as on aspects of the interaction between waste and the surrounding WIPP medium.

Actinide Conversion (Transmutation)

The idea of separating out the actinide elements (uranium plus the transuranics) from high-level waste created from spent fuel in commercial nuclear reactors and of recycling the actinides to a reactor has been considered for some time. Removal of actinides from the waste could conceivably remove a significant portion of the long-lived radioactive hazard; putting the actinides back in a nuclear reactor or accelerator can result in a reduction of their radioactivity as a result of fission or conversion

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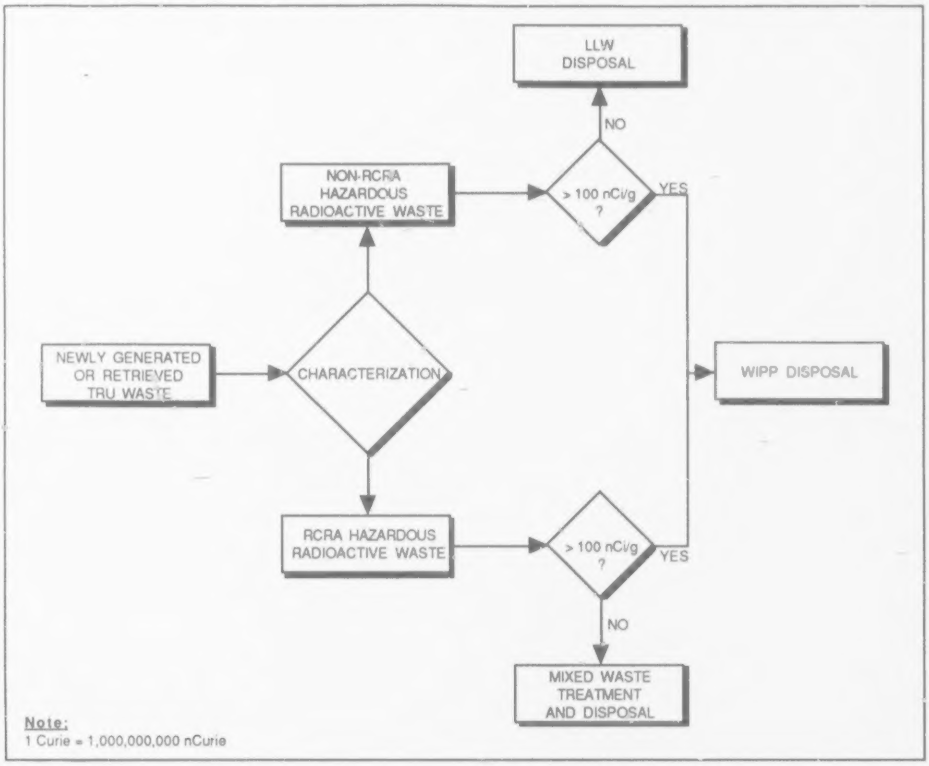
[68] Ibid.

Figure 2-10—Characterization of Transuranic Waste To Determine Disposal Option


LLW DISPOSAL
NO
NON-RCRA HAZARDOUS RADIOACTIVE WASTE
> 100 nCi/g ?
YES
NEWLY GENERATED OR RETRIEVED TRU WASTE
CHARACTERIZATION
WIPP DISPOSAL
RCRA HAZARDOUS RADIOACTIVE WASTE
> 100 nCi/g ?
YES
NO
MIXED WASTE TREATMENT AND DISPOSAL

Note:
1 Curie = 1,000,000,000 nCurie

SOURCE: U.S. Department of Energy, "Applied Research, Development, Demonstration, Testing and Evaluation Plan," Draft, 1989.

(transmutation)[69] to shorter lived isotopes. However, as Benedict et al. point out in a 1981 book, (14) "The reduction of the ingestion hazard after recycling equilibrium has been reached will be only modest, and the technical effort will be enormous. The technology for actinide partitioning is not available as yet, and considerable development will be required to make it available. Moreover, it has to be considered that part of the actinides are transferred from the waste to the fuel cycle on recycling, where they may create an even greater hazard than the waste."

Although these authors are skeptical about the benefits of actinide separation for high-level waste, they are more optimistic about treating TRU waste in this manner. They point out that for some forms of TRU waste, actinide recovery could appreciably reduce the ingestion hazard of the waste because of the relatively low fission product concentration compared to high-level waste.[70] Furthermore, it should be simpler technically to accomplish this for TRU waste than for high-level waste (15).

A more recent (1989) analysis of actinide conversion by Rockwell International is somewhat more positive. The Rockwell authors believe that whereas aqueous reprocessing does not lend itself well to actinide conversion[71] the development of a new concept involving pyrometallurgical processing of fuel from a metallic fast reactor could ultimately yield economic benefits, compared to the disposal of spent fuel in the commercial sector. In addition, according to the Rockwell report, risks due to accidents or environmental contamination would be reduced. In the Rockwell concept, not only are "minor actinides" (i.e., nonplutonium actinides) reduced at the rate of about 5 percent per year in a dedicated facility for that purpose, but technetium-99, a long-lived radionuclide that tends to follow LLW, is also transmuted to shorter-lived radionuclides after separation and return to a reactor. Separated strontium-90 and cesium-137 are handled by allowing them to decay for a hundred years or so rather than transmuting them or putting them in a facility for 10,000-year waste (39).

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[69] The terms *transmutation* and *partitioning*, or just *transmutation*, are often used to characterize what we have called *actinide conversion*. Transmutation involves converting one chemical element or isotope into another by a nuclear reaction. In principle, long-lived radioisotopes in nuclear wastes could absorb neutrons in a fission reactor or a future fusion reactor and be converted into short-lived or stable isotopes. A practical system would need to be capable of separating or partitioning isotopes in a special reprocessing system, and fabricating the long-lived ones into a form for further irradiation. (See R.L. Murray, Understanding Radioactive Waste, 3d ed., Batelle Press, 1989, p. 123.)

[70] Presumably this analysis also holds for inhalation hazards, the principal concern about alpha-emitting radionuclides such as plutonium.

Although the Rockwell concept is directed primarily at the commercial sector, it might apply to the defense sector. In the latter, reprocessing to recover plutonium is an accepted practice and major goal, in contrast to the commercial sector where concern about the proliferation of plutonium has been a factor in the United States not encouraging such activity. In many ways, a facility that permits partitioning of the waste and transmutation of certain targeted radionuclides, which will drastically reduce the long-lived radionuclide population, is an appealing concept. Additional research in this direction could well be valuable, particularly if long delays in repository opening persist.[72] However, the integrated fast reactor and pyrometallurgical fuel processing facility are far from functional realities and would require the development of an entirely new nuclear fuel cycle. Both pyroprocessing and an aqueous process known as Thorex are being worked on by two different groups at Argonne National Laboratory. Each must contend with the fact that only a fraction of the TRU radionuclides loaded into a reactor is transmuted in a given cycle.

At least a decade or two will probably be required before actinide conversion becomes a practical possibility and the costs could be high.[73] Thus, in the short run, actinide conversion does not appear to be a significant factor in high-level or TRU waste management.[74] Nevertheless, converting TRU elements in tank waste to useful elements through a new "waste burn" technology is one of the rationales put forward in a Westinghouse report to prevent DOE from eliminating funding for the Fast Flux Test Facility (92).

Waste Minimization

One element of the RDDT&E plan involves research on the minimization of waste from plutonium manufacturing and processing. TRU and byproduct waste are generated by all plutonium-related operations, including raw materials, component manufacture, scrap reprocessing, or reclamation. Currently, typical reprocessing of plutonium oxides and scrap is performed pyrochemically or via aqueous methods involving nitric or hydrochloric acid. Research is striving to improve plutonium yields, reduce the quantities of scrap, reduce waste and processing of byproducts, and reduce hazardous chemicals and the amount of mixed waste. Among the opportunities for minimization listed by DOE are forming blanks closer to final size, improving the precision of machining operations, using robotics and automation in handling operations, and improving plutonium recovery by employing fewer chemicals and producing less plutonium-bearing waste (53).

Research and development on the minimization of waste from plutonium manufacturing and processing could yield real benefits, in terms of reducing both the amount of waste to be treated or disposed of and the safety and health threats to workers. It should be vigorously pursued.[75]

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[71] By contrast, it has been stated elsewhere that separation by pyroprocessing is not as good as aqueous processing. Source: L. Lidsky, Professor of Nuclear Engineering, Massachusetts Institute of Technology, personal communication, Apr. 30, 1990.

[72] The Japanese are reported to be moving ahead with a 10-year research effort, the Omega program, to create a system to transmute radioactive nuclides in spent fuel using proton and electron accelerators. (See Nuclear Waste News, Nov. 29, 1990, p. 467.)

[73] This view is supported by Lidsky, who believes that 10 years from now, actinide conversion would not be a reality; he views it more as a technology of last resort. Source: (Lidsky, L., op. cit., footnote 20.)

[74] This view is supported by a March 1990 statement by the Radioactive Waste Management Committee Bureau of the Organization for Economic Cooperation and Development/Nuclear Energy Agency.

[75] There is some indication of forward movement in this regard at DOE. At the February 1991 Waste Management Conference in Tucson, AZ, it was announced that DOE had reallocated 25 percent of its FY 1990 process developmetn funds, some $44 million, to waste minimization R&D. The fraction allocated to TRU waste minimization was not indicated.

THE REGULATORY FRAMEWORK

Introduction

The regulatory framework for TRU waste is a complicated one. There are some similarities between regulation of TRU and high-level waste and some differences. TRU waste, as a distinct category, was not formally defined until 1974, when the U.S. Atomic Energy Commission (AEC) proposed new radiation protection standards in the *Federal Register* (20); prior to that, it had not been distinguished from LLW. The current definition of TRU waste both in a Department of Energy (DOE) order and as codified by the Environmental Protection Agency (EPA), is quite quantitative and specific. It also differs from the earlier definition in that the previous lower radioactivity limit of 10 nanocuries per gram has been increased by a factor of ten.

TRU waste is generated, buried, or stored at a number of DOE Weapons Complex sites. Plans call for stored and newly generated waste to be treated, certified, and transported to the Waste Isolation Pilot Plant (WIPP) for disposal. Thus, as many as 22 States in addition to the Federal Government have a regulatory stake in the management of TRU waste within or moving through their boundaries. In addition, much TRU waste is mixed waste.[76] Whereas much high-level waste (HLW) is also mixed waste, in the latter case the relative hazards are believed to be such that safe handling of the radioactive component will in many instances ensure safe handling of the hazardous component. For some TRU waste, however, the hazardous component may assume more importance. The regulatory framework thus encompasses a wide spectrum of elements—DOE orders; EPA and NRC standards; and various agreements among Federal, State, and other parties.

Although the Nuclear Regulatory Commission was given regulatory authority over civilian nuclear power, its role in connection with defense sites is very limited. Because TRU waste is almost exclusively a product of defense activity, DOE, through the mechanism of DOE orders that are not codified, retains considerable regulatory authority over its own activities.

Definition of Transuranic Waste

In *Nuclear Imperatives and Public Trust: Dealing With Radioactive Waste*, L. Carter provides some historical background concerning the definition of TRU waste. Evidently, TRU waste was not explicitly defined until 1974 when the Atomic Energy Commission proposed a rule (10 CFR Parts 20 and 50) defining TRU waste as any material with 10 nanocuries of TRU radionuclides per gram (20). Carter cites this proposed regulation as one of a series of events that worked against the development of a commercial reprocessing facility at Barnwell, SC: "To establish this threshold, at a level almost too low to be measured, meant that large amounts of general-process trash at Barnwell, which otherwise might have been regarded as ordinary LLW and disposed of as such, now would have to be kept in retrievable storage and eventually shipped to a geologic repository" (20). Carter points out that the proposed rule never took effect and was superseded by NRC regulations in 1982 setting the lower limit for TRU waste at 100 nanocuries per gram. By that time, the Barnwell Plant had been abandoned, in part due to U.S. concerns about plutonium proliferation.

The new definition places TRU waste somewhere in between HLW and LLW.[77] However, at the upper end of the TRU waste definition, there appears to be no clear demarcation between TRU and high-level waste. The concentration of transuranics in Hanford soil is reported to be as high as 40,000 nanocuries per gram on the surface (22). According to current waste acceptance criteria, remote-handled TRU waste containers with surface dose rates as high as 1,000 rem per hour may be shipped to WIPP (72), equaling or exceeding the surface dose rates estimated for some defense high-level waste canisters.

A meeting that appears to have been instrumental in changing the definition of TRU waste took place at Gaithersburg, MD, in August 1982. Representatives of the program committee for that Workshop on Management of Alpha-Contaminated Waste were, with the exception of one EPA representative, all DOE employees or contractors. The program committee concluded that "a level of 100 nCi [nanocuries] of long-lived alpha contamination per gram of waste, averaged over the contents of a waste package, can be designated as a concentration of long-lived alpha-emitting radionuclides in LLW destined for near surface disposal that is unlikely to result in exceeding present dose limits" (13). In 1984, EPA codified this result in the *Federal Register* by making 100 nanocuries per gram the lower limit for the definition of TRU waste. Evidently, there were no objections during the public comment period.

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[76] This is illustrated by the fact that 62 percent of all retrievably stored TRU waste through 1988 was at the Idaho National Engineering Laboratory (INEL) and, of this, approximately 95 percent was suspected to be mixed waste. (See J. Solecki, "INEL Waste Management," viewgraph C8 4870, 1989.) A somewhat lower percentage, 40 percent, of all TRU waste stored at eight sites managed by DOE Albuquerque operations (excluding INEL and Rocky Flats) is estimated to be mixed waste as of December 31, 1989. (See R. Ortiz, U.S. Department of Energy Albuquerque Operations Office, personal communication to P. Johnson, Apr. 10, 1990.)

[77] In the mid-1980s, an effort was made to revise the definitions of high-level, TRU, and low-level wastes but to no avail. For a useful discussion, see the report by Kocher and Croff (29).

The impetus for changing the lower bound of the TRU waste definition from 10 to 100 nanocuries per gram could have been due to a variety of factors. Improvements in assay techniques were making it possible to measure transuranics down to the 100 nCi/gm level. If it is easier and cheaper to dispose of LLW than TRU waste, the lower bound has considerable economic importance. It could affect such matters as how much cleanup must be done on pre-1970 buried waste at defense sites and how much must be packaged to go to WIPP. Thus, costs and benefits must be considered. It has been estimated that the redefinition of TRU waste served to reduce the volume of plutonium-contaminated soil at Hanford from 400 million to 100 million cubic feet. The redefined 300 million cubic feet would then be subject to less stringent cleanup standards, thus reducing the cost but increasing the risk.

The draft Environmental Impact Statement (EIS) by EPA for disposal standards for TRU and high-level waste (40 CFR 191) that was remanded by a court seems to treat TRU waste as a corollary to high-level waste: "The proposed standards [for spent fuel and high-level waste] also apply to wastes containing alpha-emitting TRU nuclides with half-lives greater than 1 year[78] at concentrations greater than 100 nanocuries per gram" (87). After pointing out that alpha-emitting TRU nuclides constitute a special type of hazard because of their long half-lives and high radioactivity, the draft EIS cites two or three studies that provide some guidance as to what the concentration level at the interface between TRU and LLW might be and concludes that TRU waste with concentrations higher than 100 nanocuries per gram should be included under EPA standards. However, the scientific evidence does not appear convincing. Based on the same data, a different lower limit (i.e., 10 nanocuries per gram) could have been defined.

A definition is not a safety standard. The grouping of TRU waste with high-level waste in developing EPA disposal standards indicates that these two wastes have something in common that requires somewhat similar disposal. TRU waste, unlike LLW, is supposed to be placed in a repository rather than disposed of at or near the surface. This is consistent with DOE and predecessor agency policy back to the 1970s when the WIPP idea originated. However, regardless of the definition, waste—whatever the category—must meet certain disposal standards that, according to the present system, are determined by the radiation dose and the risk to individuals under a variety of scenarios.

Regulations Affecting Transuranic Waste

Buried Waste

At a National Academy of Sciences meeting on buried TRU waste at the Idaho National Engineering Laboratory (INEL), the principal DOE contractor, EG&G-Idaho, described the risk and performance assessment work underway concerning alternative methods of dealing with buried TRU waste in the Subsurface Disposal Area (SDA) at INEL. A summary of the approach follows.[79]

Because of the mixed nature of the waste, both health-based risk assessments concentrating on short-lived effects and performance assessments focusing on long-term risks must be considered. Health-based risk assessments conducted under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) involve identification of contaminants, exposure assessment, toxicity assessment, and risk characterization.[80] The health-based risk assessment at the SDA is currently in the early stages, as part of the Remedial Investigation/Feasibility Study (RI/FS) process. Performance assessment at an existing burial site raises many questions: What requirements apply? What intrusion scenarios should be considered? What siting criteria apply? What waste acceptance criteria apply? What type of data are needed?

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[78] The half-life limit was changed to 20 years in the "final" standard.

[79] R.R. Piscitella, EG&G Idaho, "Overview of Risk/Performance Assessment," presentation with viewgraphs made to the National Academy of Sciences Panel to Review the DOE Assessment of Pre-1970 Buried Waste at the Idaho National Engineering Laboratory, November 1989.

[80] 42 U.S.C.A. §§6904(i)(6)(A)-(F) (West Supp. 1990).

A problem associated with EG&G's SDA performance assessment concerns the lack of appropriate regulations for old burial sites. EG&G's approach, as presented at the National Academy of Sciences panel meeting, was to apply regulations for new geologic disposal sites to the old burial sites, as illustrated by table 2-5. EG&G concluded that "performance assessment will require using applicable parts of regulations that were written for new disposal sites" and that "DOE orders, CFRs, and other ARARs [applicable or relevant and appropriate requirements] that apply to SDA risk assessments will be identified in the RI/FS work plan."[81] However, some members of the panel objected to applying EPA regulations for new deep repository sites (40 CFR 191) to the old shallow land burial sites. Furthermore, the regulations for repositories have been remanded by a court and must be reissued.

Table 2-5—Potential ARARs for Assessment of Buried Waste at the Subsurface Disposal Area at INEL

Applicable or Relevant and Appropriate Requirements (ARARs)	Source
1. For 1,000 years of groundwater protection • 15 picocuries/liter of alpha-emitting radionuclides • Beta or gamma radiation, annual dose equivalent 4 millirems	40 CFR 191
2. For 1,000 years of human protection—all pathways annual dose equivalent • 25 millirems whole body • 75 millirems critical organ	40 CFR 191/ 10 CFR 61
3. For 10,000 years to have less than one chance in 10 of exceeding limits defined in this CFR	40 CFR 191
For 10,000 years to have less than one chance in 1,000 of exceeding 10 times the limits defined in this CFR	40 CFR 191
4. For protection from inadvertent intrusion at any time after institutional control	10 CFR 61
5. To maintain radioactive exposures as low as reasonably achievable (ALARA)	10 CFR 61

SOURCE: Adapted from J. Solecki, "INEL Waste Management," viewgraph C8 4870, 1989.

In November 1989, INEL was placed on the National Priorities List (NPL) under CERCLA.[82] Some work on risk assessments was underway during 1990 on certain remedial actions associated with buried TRU waste, namely, retrieval of the waste, vapor vacuum extraction of subsurface organic vapors, and in situ vitrification.[83] Furthermore, alternative strategies for remediating the buried TRU waste have not yet been thoroughly evaluated.[84]

Waste Storage

The rules applicable to TRU waste storage encompass the following: EPA regulations governing the hazardous component of the mixed TRU waste (particularly those referred to as land-ban restrictions), State imposed restrictions (e.g., the decision by the Governor of Idaho not to accept any more Rocky Flats waste and the decision by the Governor of Colorado to limit the volume of mixed TRU waste that can be stored at Rocky Flats), DOE orders (particularly those dealing with purely radioactive materials), and requirements of Federal Facility Agreements, Consent Orders and interagency agreements involving EPA, DOE, and State agencies.

EPA land disposal restrictions for hazardous and radioactive mixed waste generally prohibit or ban the storage or disposal of hazardous waste unless it is treated according to EPA-approved methods. At present, there is a 2-year variance from these restrictions, due to a lack of treatment capacity. Since much TRU waste is mixed waste (i.e., it has both hazardous and radioactive components), it is generally covered by the present variance from the land ban rules.[85]

Certification and Transport of Waste to the Waste Isolation Pilot Plant

According to the DOE 1989 Five-Year Plan, "The Waste Acceptance Criteria Certification Committee (WACCC), consisting of representatives from EPA, the State of New Mexico, and DOE, negotiated and established stringent criteria on the form of waste acceptable at the Waste Isolation Pilot Plant" (60). However, this statement is contradicted in the WIPP Supplemental EIS. The latter document says that the Waste Acceptance Criteria (WAC) for WIPP were "developed by a DOE-wide committee of experts. . . ." Furthermore, the WACCC was established in 1979, prior to EPA becoming involved in WIPP (31). The role of a more broadly based WACCC, involving groups outside DOE, seems to be limited primarily to ensuring compliance with the acceptance criteria that DOE established (73). For example, even though EEG has participated on audit teams in certification reviews, their review can be accepted or rejected by DOE.[86] This situation could be significant, if outside parties seek to influence the outcome of the debate about modifying the waste form for WIPP.

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[81] Ibid., viewgraph 9-10174.

[82] W.N. Sato, U.S. Department of Energy, viewgraph E90-0636 at National Academy of Sciences Panel Meeting on Buried TRU Waste at Idaho, Mar. 20-21, 1990.

[83] R.R. Piscitella, Presentation at National Academy of Sciences Panel Meeting on Buried TRU Waste at Idaho, Mar. 20-21, 1990.

[84] In analyzing alternatives for remediating buried waste at INEL, historical and political factors must be considered. According to a DOE presentation made to the OTA project team during a visit to INEL in 1989, commitments were made on three separate occasions, twice in 1970 and once in 1973, by AEC officials to remove buried waste from Idaho. (See Solecki, J., "INEL Waste Management," Viewgraph c9 0084, 1989.)

[85] In June 1990, recognizing lack of treatment capacity nationwide, EPA issued a 2-year variance from the mixed waste land disposal regulations. An extension to this variance of up to 1 year, which may be extended for an additional year, can also be obtained upon request on a case-by-case basis. (See Land Disposal Restrictions for Third Thirds Schedule Wastes, 44 F.R. 22320, 22644 (1990); and Procedures for Case-by-Case Extensions to an Effective Date, CFR §268.5 (1989).)

According to the 1989 Five-Year Plan, DOE shipments of radioactive material are regulated primarily by the Department of Transportation and the NRC; EPA and the Interstate Commerce Commission also have regulatory roles. DOE also indicates that it abides by State, Indian tribal, and local regulations "consistent with Federal requirements. Regulations cover design and testing of the transport package; shipment identification including labeling, marking, placarding, and preparing shipping papers; package and vehicle inspections; and routing and driver training for spent fuel and high-level waste" (63).

In 1989, the NRC approved the TRUPACT-II container design for use in shipping contact-handled TRU waste to WIPP. However, beginning late in September 1989 and continuing into the first half of 1990, the NRC found a variety of manufacturing defects in the initial 15 TRUPACT-II containers during routine inspections which led the NRC to notify DOE and the manufacturer, the Nuclear Packaging Division of Pacific Nuclear Corporation (NUPAC), of noncompliance. An NRC inspection in late August 1990 of six new TRUPACT-II units in various stages of completion revealed that the units and manufacturing processes were inadequate. It is alleged that earlier, NUPAC had filed a request to the NRC "on behalf of the Department of Energy" to amend the specifications in the standards for the dimensions of the containers so that the 15 original containers manufactured by NUPAC would be acceptable; NRC turned down NUPAC's petition.[87]

The issue of safe transportation of waste to WIPP will undoubtedly continue to be an area of technical and public concern.

Regulations Affecting the Waste Isolation Pilot Plant

The function of WIPP, as set forth in the Department of Energy National Security and Military Applications of Nuclear Energy Act of 1980 (Public Law 96-164), is to serve "as a defense activity of the Department of Energy. . . for the express purpose of providing a research and development facility to demonstrate the safe disposal of radioactive waste resulting from the defense activities and programs of the United States exempted from regulation by the Nuclear Regulatory Commission" (64). From the outset, certain oversight activities were established through legislation. The original legislation authorizing WIPP requires that the Secretary of Energy consult and cooperate with appropriate officials of the State of New Mexico concerning health and safety concerns and that a written agreement be entered into by the two parties specifying procedures for such cooperation and consultation. That agreement has been modified several times since its enactment (69).

DOE must comply with a variety of Federal requirements applicable to WIPP, including the National Environmental Policy Act (NEPA), RCRA, and EPA disposal standards for TRU waste (69). Under NEPA, a Record of Decision must be issued by the Secretary of Energy subsequent to having received comments on the Supplemental Environmental Impact Statement. Under RCRA provisions, DOE must show, in a "no-migration" petition to EPA, that the hazardous component of the waste to be placed in WIPP will not migrate. DOE must also demonstrate that radioactive materials in the repository will conform to EPA disposal standards (40 CFR 191) for TRU waste.[88] These standards are being reformulated by EPA after having been remanded by the 1st Circuit Court of Appeals in Boston because they allowed higher levels of radionuclide contamination of drinking water than in the Safe Drinking Water Act.[89]

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[86] R. Neill, Environmental Evaluation Group, personal communication, June 29, 1990.

[87] *Weapons Complex Monitor*, Sept. 17, 1990, pp. 19-20.

[88] There is an important distinction between DOE demonstrating compliance with EPA disposal standards for radioactivity and EPA-RCRA standards for migration of hazardous waste. In the latter case, EPA determines whether DOE has complied, whereas for radioactivity, DOE determines compliance, i.e., self-compliance.

In September 1990, the Board of Radioactive Waste Management of the National Research Council (BRWM) convened a Symposium on Radioactive Waste Repository Licensing in response to "widespread scientific concern and interest in the revisions being made during the remand of 40 CFR Part 191."[90] Among those concerns was a recommendation expressed to the chairman of the NRC by the Commission's Advisory Committee on Nuclear Waste, that:

> . . . the Commission object to the EPA standards on the basis that
>
> —There are no obvious ways for demonstrating compliance of any specific repository site with the Standards. In this sense, the Standards may be unrealistic.
>
> —The Standards are also overly stringent and inconsistent. There is strong evidence that they will be wasteful of resources with little commensurate interest.[91]

The BRWM convened the Symposium shortly after issuing a position statement entitled "Rethinking High-Level Radioactive Waste Disposal."[92] That statement indicates that, given what the BRWM characterizes as the current highly inflexible U.S. technical approach to high-level waste disposal coupled with the U.S. regulatory approach, it is unlikely that effort will succeed. The BRWM proposes an alternative approach that they believe will "require significant changes in laws and regulations, as well as in program management."[93] Although the BRWM statement focuses on high-level waste disposal, its analysis of regulations and standards is relevant to TRU waste disposal.

At the symposium, the Environmental Evaluation Group (EEG) defended the current approach being used by EPA in setting the disposal standard as follows:

> Reasonable confidence in the prediction of site behavior for 10,000 years or more is achievable using well-established principles of geosciences. EPA's approach of probabilistic release limits with flexibility in the implementation of the Standard is a sound one. EEG believes that the numerical basis of the Standard is set at a level that is reasonably achievable for a good site that is properly engineered, and should not be significantly relaxed.[94]

In arriving at this conclusion, EEG pointed out that any drastic change from the 1985 (remanded) standard might delay the issuance of a final standard for several years, causing uncertainties at WIPP. In addition, if the new Standard were to differ significantly from the remanded one, it would greatly increase the probability of a remand of the new standard.[95]

A distinction has developed between the regulatory compliance required for a fully operational WIPP facility and that required for an initial set of experiments in WIPP. On November 14, 1990, EPA published its decision to rule in favor of DOE's no-migration petition, conditional upon DOE activity being limited to an initial test phase.[96] EPA thus will allow DOE to emplace waste in WIPP for the test phase without demonstrating that ultimate disposal standards will be met. The decision is justified by the research nature of the experiments and the fact that the waste will be retrievable, if necessary, during and immediately after the test phase. However, in so doing, EPA is allowing a different path to be taken for WIPP than for the high-level waste repository; in the latter, current policy is that construction cannot begin until compliance with long-term disposal standards is demonstrated.

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[89] "EPA Waste Regulation Comes Under Fire at National Research Council Meeting," *Nuclear Waste News*, Sept. 20, 1990, p. 366.

[90] Letter from Frank L. Parker, BRWM, to John H. Gibbons, OTA, Aug. 22, 1990.

[91] Ibid., p. 1.

[92] National Academy of Sciences, "Rethinking High-Level Radioactive Waste Disposal: A Position Statement of the Board on Radioactive Waste Management" (Washington, DC: National Academy Press, 1990).

[93] Ibid., p. 5.

[94] R.H. Neill, J.K. Channell, and L. Chaturvedi, "New Mexico Environmental Evaluation Group Perspective on Transuranic and High-Level Waste Disposal Regulations," paper presented at Symposium on Radioactive Waste Repository Licensing, Board on Radioactive Waste Management, Washington, DC, Sept. 17-18, 1990, p. 2.

[95] Ibid., p. 11.

[96] Conditional No-Migration Determination for the Department of Energy Waste Isolation Pilot Plant (WIPP), 55 Fed. Reg. 47700 (1990).

In an October 1989 briefing by DOE about its plans for WIPP, the decision of whether to move ahead with the test phase was asserted to be the prerogative of the Secretary of Energy. In the DOE presentation, three categories of action were listed as being necessary to move forward: technical internal actions for which approval rests within DOE; technical external actions for which approval or comment resolution is required from external organizations such as EPA or EEG; and "institutional" issues (58). DOE has since focused considerable attention on the latter category in order to keep the WIPP program moving forward according to their plans. For example, once the conditional no-migration petition was issued by EPA, the biggest remaining obstacle to placing the first experimental waste package in WIPP was accomplishing land withdrawal. Since Congress did not proceed to enact land withdrawal legislation, DOE obtained the necessary land administratively in early 1991. Thus, although there are some checks and balances, the WIPP project remains to a considerable extent under the control of the Department of Energy.

DISCUSSION

Definition of, and Standards for, Disposal of Transuranic Waste

The change in the early 1980s of the lower limit in the definition of TRU waste from 10 to 100 nanocuries per gram of alpha radioactivity allowed more waste to be classified and treated as LLW. This shift, given current disposal practice and plans that call for LLW to be disposed of at or near the surface (whereas TRU waste requires deep geologic repository disposal), is expected to result in tens or hundreds of millions of dollars in savings. However, irrespective of definition, the waste, whatever its classification, must satisfy the standards set for its disposal.

The Environmental Protection Agency (EPA) is in the process of reissuing disposal standards for spent fuel, high-level waste (HLW), and TRU (40 CFR 191); as a result of a lawsuit by several States and environmental groups, an earlier version of the standards was found wanting by the First Circuit Court, Boston, and remanded.[97] A second working draft of the revised standards was issued for comment in 1990. When promulgated, these standards will apply to the Waste Isolation Pilot Plant (WIPP) if and when it becomes operational as a disposal repository for TRU waste. These standards will be subject to debate, both within the technical community and the public at large. Among the issues that might be debated are the length of time that the waste must be isolated from the environment and the desirability of being able to retrieve the waste at some future date.

Repository Delays; Alternative Storage and Disposal Strategies

Retrievably stored TRU waste at Department of Energy (DOE) sites is located at 10 Weapons Complex sites, generally as loosely packed material in 55-gallon drums stored at or near the surface. The nominal design lifetime of the drums is about 20 years; some have already reached that limit. Current plans call for TRU waste to be shipped to a deep geologic repository for disposal in a form not very different from its current form. The only possible repository available for the stored waste is the Waste Isolation Pilot Plant near Carlsbad, NM. Construction of WIPP is essentially complete. As of early 1991, however, no experiments have yet been performed involving placement of waste in the facility to aid in determining if WIPP is a suitable facility for long-term disposal of TRU waste. In addition, even if the earliest date—1995—for opening WIPP on an operational basis is achieved, it will take 25 to 30 years to fill the facility with currently stored and yet-to-be generated TRU waste.

There is thus a need to identify other alternatives for short-, intermediate- and long-term storage of TRU waste. In the short term, DOE is confronted with the mixed TRU waste that has been accumulating at the Rocky Flats Plant since September 1989 when the Governor of Idaho refused to allow further shipments to the Idaho National Engineering Laboratory (INEL). Although the start-up of a supercompactor in 1991 may ease the situation somewhat, among the options DOE has been exploring are sending the waste to other DOE facilities, to Federal non-DOE facilities, or to privately owned facilities. Each option is likely to encounter resistance from States and citizens. The policy implications of the privatization option, which DOE appears to be pursuing (147), require careful scrutiny. Putting defense TRU waste in the care of a private contractor at privately owned facilities is a major break with past U.S. Government practice.

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[97] NRDC v. EPA, 824 F. 2d 1258 (1st Cir. 1987); 26 ERC 1233, July 17, 1987 as amended Sept. 24, 1987; "Court Remands Nuclear Waste Site Rules, Cites Conflict with Drinking Water Law" *Current Developments*, Sept. 24, 1987, p. 848.

If further significant delays occur in the opening of a TRU waste repository, which could very well be the case,[98] retrievably stored TRU waste may have to be treated so that it can be safely stored on-site for longer periods than is now possible, given the present condition of the waste. Some of the six new TRU waste treatment facilities planned for 1992-99 could provide needed treatment capability. Planning for extended storage and enhanced treatment could also be compatible with the possible need to change the waste form to prevent gas generation in packages placed in the repository. The level of treatment desirable requires careful study; final recommendations of the Engineered Alternatives Task Force (EATF) for the WIPP project are expected in 1991 and should provide valuable information.

Remediation of Buried Waste

The volume of buried TRU waste at Weapons Complex sites well exceeds that of retrievably stored TRU waste. Yet plans for remediating buried waste at Idaho, Hanford, and other sites are not very developed. Considerable attention is focused on one technology—in situ vitrification—which, although promising, may be of limited utility because of economic and other factors. Several alternative strategies need to be examined, with input from the public. If, in fact, the costs and occupational radiation exposures are considerably lower when waste is remediated on-site without exhumation, local communities will have to be convinced that the waste will not contaminate local water supplies or otherwise threaten public health. Careful research and monitoring as well as a credible outreach program will be necessary to provide such assurance.

The Waste Isolation Pilot Plant

In accordance with DOE planning and congressional intent, WIPP has remained a central element in DOE strategy for managing TRU defense waste. The WIPP geological salt bed facility has been constructed at a cost of about $700-800 million to serve as a research and development facility for TRU waste disposal. After a 5-year experimental phase, WIPP could become the final resting ground for retrievably stored and yet-to-be generated TRU defense waste. Secretary of Energy James D. Watkins developed a detailed decision plan, which was revised frequently, to help him decide whether to go ahead with WIPP; in June 1990, he made a positive decision on WIPP's readiness to proceed with a limited number of experiments. At present, the consensus of the various DOE technical oversight bodies supports preparation for limited emplacements of TRU waste in WIPP, in an attempt to resolve uncertainties prior to deciding whether to proceed with full operations.

WIPP currently represents the closest the United States has come to placing radioactive waste in a deep geologic repository, the option currently favored by DOE, EPA, and the Congress for disposal of both TRU and HLW. Although placement of the first waste package in WIPP will be for experimental purposes only, and although the package so placed must be retrievable (in contrast to plans for operational disposal), such placement, if it occurs, will have symbolic importance. It could signify that after all these years the United States is finally doing something about TRU radioactive waste disposal. A degree of confidence could be restored in the ability of U.S. science and technology to eventually solve this tough radioactive waste disposal problem.

However, at this writing WIPP is still not a certainty. Matters that may still need attention prior to the start of the experimental phase include: DOE's operational readiness for radiation protection, monitoring, and other technical matters; resolution of the differences between DOE and the State of New Mexico concerning funds for highway improvements related to the transport of waste to WIPP.[99]

Congressional debate and legislation remain vehicles for those who either oppose WIPP entirely or wish to place certain conditions on its operations. For example, in 1991 the New Mexico congressional delegation introduced legislation to cancel the administrative withdrawal of land from the DOI to DOE.[100]

Two outstanding issues that pertain to WIPP's long-term performance as a repository are the adequacy of the present waste form and the nature of the final waste disposal standards for WIPP. At the April 26, 1990 WIPP hearings, there appeared to be a consensus among a wide spectrum of technical oversight individuals that the present TRU waste form could well prove unsatisfactory for two reasons: gas generation within the waste packages could result in situations that are too uncertain to predict with sufficient confidence; and EPA disposal standards for TRU waste might not be achievable, particularly under human intrusion scenarios. Disagreement centered on what to do about this situation. On the one hand, DOE is studying alternative waste forms and believes that the experiments will provide useful information. On the other hand, some believe that the experiments are not likely to shed further light on the situation, whereas improving the waste form will be valuable whether or not WIPP becomes operational. There was no discussion of how the waste form might be altered or at what cost. A study of possible options to the present TRU waste form is underway. It should provide a basis for evaluating options given the limitations of existing retrievably stored TRU waste, as well as uncertainties concerning the geologic repository.

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[98] Under one scenario presented at a May 24, 1990, DOE Working Session on the WIPP Decision Plan and Rocky Flats Plant Alternative Storage Options, WIPP's startup is delayed until the year 2003 or 2004 due to the need to build and operate an alternative treatment facility for TRU waste.

[99] See also R.H. Neill and L. Chaturvedi, "Status of WIPP Project," paper presented at Waste Management '91, Tucson, AZ, February 1991.

[100] K. Schneider, "Plan on Starting Nuclear Waste Clears Big Hurdle," *The New York Times*, Jan. 23, 1991.

A second broad issue concerns the disposal standards themselves. The disposal standards are currently being reworked. The Advisory Committee on Nuclear Waste of the NRC believes the standards are too strict. However, EEG has pointed out that EPA in 1982 relaxed the standard for permissible release of transuranics from a repository, compared with high-level waste, by a factor of 3, after WIPP officials expressed concerns about meeting the previous limit.[101] As a result, because a TRU repository need comply with lower standards than a high-level waste repository, EEG opposes any further relaxation of the standard.

Disposal standards are an important consideration for those concerned about health and safety. Some have argued that no experiments should be allowed in WIPP until DOE demonstrates compliance with long-term disposal standards. The NRC holds that construction of a high-level waste repository in Yucca Mountain, NV, cannot begin until compliance with disposal standards is demonstrated. However, key decisionmaking authority for WIPP rests with DOE, not NRC. Also, DOE's position is that the experiments will be retrievable—it is not yet disposing of waste. DOE does not expect to be able to comment on WIPP's ability to meet disposal standards until completion of the performance assessment in 1994 or 1995.[102]

Finally, demonstrating that a geologic repository can safely contain waste for ten thousand years or more is a daunting task. When the WIPP facility is operational, waste in a TRU repository, as currently envisioned, will be irretrievable. Future generations might not consider these acceptable conditions. There are no easy solutions, but all options should be considered with as much public involvement as possible if WIPP is to receive full support.

Waste Minimization

Minimization of TRU waste is an area that might yield dividends in terms of easing the burden of cleanup and waste management. One promising area identified by DOE is in plutonium processing and manufacturing operations (53). DOE indicated in April 1990 that approximately $26 million (annually) is budgeted for research and development related to waste minimization[103] (85). It is not clear how much of this will be devoted to plutonium operations.

If waste minimization is defined as reducing the generation of new waste, then very little is being done in the area of TRU waste minimization. As DOE has indicated, "high-level and transuranic wastes have not yet been given sufficient attention and emphasis in waste minimization planning" (86). Emphasis has been on reclassifying a portion of existing TRU waste as LLW and segregating hazardous from TRU materials. These are conceptually different from waste minimization and could *increase* the amount of waste of all kinds to be disposed of. All indications are that TRU waste minimization is just beginning to be considered at DOE and has a long way to go before benefits are obtained. The only substantive TRU waste minimization results to date may have come about because of the shutdown of various facilities, particularly the Rocky Flats Plant and Savannah River production reactors.

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[101] J.K Channell, Environmental Evaluation Group, views on "Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level, and Tranuranic Radioactive Wastes (40 CFR 191)," presented to U.S. Nuclear Regulatory Commission, Advisory Committee on Nuclear Wastes, Mar. 23, 1990, pp. 7-8.

[102] Although OTA has not performed any in-depth study of congressional intent with regard to WIPP, the authorizing legislation would seem to indicate that it was meant to serve as a research and development facility although the January 1981 DOE Record of Decision on WIPP states that it is intended for disposal of waste. DOE's 1979 Draft Environmental Impact Statement envisioned the facility as having several functions, including serving as a full-scale repository for TRU waste as a step toward gaining experience for a high-level waste repository.

[103] Subsequently, this figure was increased to $44 million. Source: J. Marchetti, remarks at Waste Management '92, Tucson, AZ, February 1991.

Scenarios for Future Transuranic Waste Production

Planning for TRU waste management must take into account projections of yet-to-be-generated waste. The DOE Integrated Data Base (IDB) indicates that the volume and radioactivity of stored TRU waste are expected to increase substantially; however, there was a decrease in the amount projected in the IDB for 1989, compared with the IDB for 1988. The earlier volume projected an eightfold increase in TRU waste production from 1987 to 2013, whereas the 1989 projection is for a 3.5-fold increase from 1988 to 2013 (75,80). This trend has continued in the latest (1990) IDB. The 1990 projection is for only a 1.9-fold increase from 1989-2013. The lower projection could reflect a scaling down of future weapons stockpile requirements. Replacing the single scenario in the IDB by several alternative scenarios would be helpful in planning for future management of TRU waste.

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APPENDIX 2-A: CONDITIONS OF NO-MIGRATION DETERMINATION

As a condition of granting DOE's no-migration petition, EPA is requiring that the following conditions be met by DOE:

1. No wastes subject to this determination may be placed in the WIPP repository for purposes other than testing or experimentation to determine the long-term acceptability of the WIPP. In accordance with 40 CFR 268.6(e), DOE must notify EPA before it conducts any testing or experimentation not within the scope of the "WIPP Test Phase Plan: Performance Assessment," April 1990 (DOE/WIPP 89-011, Revision 0), as further explained in section IV.B.1 of this notice. Placement of waste for the purpose of conducting an operations demonstration is prohibited.

2. Wastes placed in the repository may not exceed 8,500 drums or 1 percent of the total capacity of the repository, as currently planned.

3. All wastes placed in the WIPP must be removed if DOE cannot demonstrate compliance with the standards of 40 CFR 268.6, before the expiration of this petition approval, with respect to permanent disposal of mixed waste in the repository. DOE must submit a detailed schedule for retrieval of the waste, including times for completing retrieval as quickly as reasonably feasible, no later than 6 months after a determination that the repository cannot meet standards for long-term disposal under 40 CFR 268.6 or 6 months before the expiration of this petition approval, whichever occurs first.

4. All wastes placed in the WIPP must be placed in a readily retrievable manner, as described in section IV.B.4 of this notice.

5. DOE must install and operate a carbon adsorption device designed to achieve a control efficiency of 95 percent in the discharge system of the bin experiment rooms. DOE must monitor the control device outlet airstream in accordance with the monitoring plan described in section IV.K of EPA's proposed decision (55 FR 13089) as amended by section IV.B.7 of today's notice, and it must maintain design and operating records as described in section IV.J of EPA's proposed decision, as amended by section IV.B.6 of today's notice. Records must be maintained at the WIPP facility for the term of this determination or for 3 years after they are created, whichever is longer. Records must also be main-

tained during the course of any enforcement actions for which they are relevant.

6. DOE must implement an air monitoring plan described in section IV.K of EPA's proposed decision (55 FR 13089), as amended in section IV.B.7 of today's notice. Records must be maintained at the WIPP facility for the term of this determination or for 3 years after they are created, whichever is longer. Records must be maintained during the course of any enforcement action for which they are relevant.
7. Conditions relating to waste analysis:
    (a) DOE must ensure that each waste container emplaced underground at the WIPP has no layer of confinement which contains flammable mixtures of gases *or* mixtures of gases that could become flammable when mixed with air. This prohibition must be implemented by analytical testing of a representative sample of headspace gases from each waste drum or individual container, as described in section IV.B.7 and V.F.1.a of today's notice.
    (b) DOE must analyze representative samples of the headspaces of containers to be used in the bin-scale test and compare these results to the estimated compositions provided in its petition for each waste types, as detailed in IV.B.7.b of today's notice. If the waste is not compositionally similar, as defined in tables 2 and 3 in IV.B.7.b, that waste cannot be shipped to the WIPP until the waste has been treated or modified such that it is compositionally similar to the estimates provided in the no-migration petition. In addition, as prescribed in IV.B.7.b, DOE must demonstrate the comparability of bin-scale wastes to wastes described in DOE's petition before placing waste in the WIPP for the alcove tests.
    (c) Waste analysis records must be maintained for the term of this determination or for three years after generation, whichever is longer. Records must also be maintained during the course of any enforcement action for which they are relevant. The records may be maintained at the generating site or at the WIPP facility.
8. DOE must provide to the EPA Office of Solid Waste and EPA Region VI annual written reports on the status of DOE's performance assessment during the test phase. These reports must include: a description of the tests to date and their results, modifications to the test plan, a summary of DOE's current understanding of the repository's performance, waste characterization data from pre-test waste characterization, and an annual summary of air monitoring data required in item 6 above.

Beyond these specific conditions, the wastes placed by DOE in the WIPP and DOE's activities under this variance must be consistent with those described in the petition. Under section 268.6(e), DOE must notify EPA of "any changes in conditions at the unit and/or environment that significantly depart from the conditions described in the variance and affect the potential for migration of hazardous constituents from the unit. . ." If the change is planned, EPA must be notified in writing 30 days in advance of the change; if it is unplanned, EPA must be notified within ten days.

Under section 268.6(f), if DOE determines that there has been migration of hazardous constituents from the repository in violation of part 268, it must suspend receipt of prohibited wastes at the unit and notify EPA within 10 days of the determination. Within 60 days, EPA is required to determine whether DOE may continue to receive prohibited wastes in the unit and whether the variance should be revoked.

Finally, under section 268.6(h), the term of today's petition approval runs for 10 years, that is until November 14, 2000.

SOURCE: 55 *Federal Register* 220 (Nov. 14, 1990).

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